Inland fisheries in multiple use of resources

FAO
FISHERIES
TECHNICAL
PAPER

265

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS

FAO
FISHERIES
TECHNICAL
PAPER

265

FIRI/T 265

Inland fisheries in multiple-purpose river basin planning and development in tropical Asian countries
Three case studies

Edited by
T. Petr
Fishery Resources Officer (Inland Fisheries)
Inland Water Resources and Aquaculture Service
FAO Fishery Resources and Environment Division

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS
Rome, 1985

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-43
ISBN 92-5-102327-1

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior permission of the copyright owner. Applications for such permission, with a statement of the purpose and extent of the reproduction, should be addressed to the Director, Publications Division, Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy.

© FAO 1985

PREPARATION OF THIS DOCUMENT

The Indo-Pacific Fisheries Commission (IPFC) Workshop on Inland Fisheries for Planners, at its meeting in April 1982 in Manila, stressed the need for supportive information and data relevant to fishery policy formulation and decision-making options in river basin development schemes. Among such needs was the preparation of several case studies from the region, which would critically analyse the inland fisheries component in the context of multiple use of a river basin. In response to the recommendation of the Workshop, which was further endorsed by the Working Party of Experts on Inland Fisheries of the IPFC at a meeting in January 1984 in New Delhi, the present document containing three individual case studies was prepared.

Distribution:

FAO Fisheries Department
FAO Regional Fisheries Offices
Selector SI
Authors

For bibliographic purposes this document should be cited as follows:

Petr, T. (ed.), Inland fisheries in
1985 multi-purpose river basin planning and development in tropical Asian countries: three case studies. FAO Fish.Tech.Pap.,,(265): 166 p.

This One
ZGNL-5JW-DRET

ABSTRACT

This technical paper presents three case studies of inland fisheries in the context of a multiple-use of land and water resources in the humid tropics of Asia. Two of the three river basins are situated on islands, i.e. the Agno in the Philippines and the Mahaweli in Sri Lanka; one is on mainland Asia, i.e. the Nam Pong Basin in Thailand. Although the river basins have a number of features in common, such as, for example, their size, forest cover and population density, they differ in a number of other environmental aspects and changes induced by the development taking place in their basins. Inland fisheries in all three catchments is represented both by capture and culture components with reservoir fisheries gaining in importance. The studies have shown that while the major constraint to the riverine fisheries has been identified as being the high level of transported sediments originating from eroding lands and mine waste discharge (the Agno Basin), in the reservoirs of Nam Pong and Mahaweli basins it has been the high fishing pressure, in one case non-regulated (Nam Pong), which has caused deterioration of fish stocks. Another constraint in force until recently was of a social (religious) character (Mahaweli Basin). The three studies have shown that in most situations inland fisheries can successfully develop under conditions of the multiple use of the resource.

Details are given on the current fish yields, on long-term changes (Nam Pong reservoir), on problems associated with introductions and stocking (Nam Pong and Mahaweli), and on some other aspects of reservoir fisheries and aquaculture developments in these basins. The studies have stressed the need for regular monitoring of fish stocks and fishing effort for successful management. A fishery development sub-model prepared for the Nam Pong reservoir has clearly shown the need for introducing regulatory measures of reservoir fishery, if it is to improve. One of the major constraints for sound fisheries development appears to be the lack of a coordinating river basin authority, both during the planning and design, as well as during the implementation and management phases. Among the recommendations put forward in Chapter 4 "Summary and Future Needs" are the need for improved monitoring of selected limnological, fish and fishery data, for better information on the impact of introductions, for a manual on suitable fish species for stocking the Indo-Pacific reservoirs and lakes, as well as for evaluation guidelines of technical character to advise fisheries planners and managers on measures against constraints imposed on fisheries by other uses and by human induced environmental changes.

CONTENTS

Page

1. INTRODUCTION 1

2. CASE STUDIES 1

A. The Agno Basin (The Philippines) by Elvira A. Baluyut 15-54

B. The Nam Pong Basin (Thailand) by Thiraphan Bhukaswan 55-90

C. The Mahaweli Basin (Sri Lanka) by Sena S. De Silva 91-166

3. SYNTHESIS 1

4. SUMMARY AND FUTURE NEEDS 9

5. REFERENCES 13

1. INTRODUCTION

Case studies presented in this publication aim at assessing the inland fisheries within the framework of multiple use of land and water resources in three river basins of tropical Asia. The Agno River Basin in the Philippines, the Nam Pong Basin in Thailand and the Mahaweli Basin in Sri Lanka were selected.

The rationale behind the studies was to clarify the position of inland fisheries in the context of other resource uses and their development, to identify the level of importance placed on inland fisheries development during the planning and execution period of major river basin modifications, and to investigate the ways for optimizing inland fisheries under constraints.

The three basins were selected for several reasons. They are all situated in the humid tropics of Asia, the basins are similar in size, and they are all undergoing intensive development because of the increasing demand for land and water resources as a result of increasing population pressure and demands for higher living standard.

Each river basin has also been under specific pressures and constraints. Planning and managerial practices have also differed from basin to basin.

This technical paper deals first with individual river basins as assessed by the authors of each study. This is followed by a synthesis based on the case studies, supplemented by additional information. A summary and suggestions for future needs conclude this technical paper.

2. CASE STUDIES

A. The Agno Basin (Philippines), by Elvira A. Baluyut

B. The Nam Pong Basin (Thailand), by Thiraphan Bhukaswan

C. The Mahaweli Basin (Sri Lanka), by Sena S. De Silva

3. SYNTHESIS (by T. Petr)

This synthesis is based on the three case studies as presented by the individual authors, and on information obtained from several additional sources available to the Editor. The conclusions reflect the Editor's opinion and may not necessarily agree with those of the authors.

3.1 The Agno Basin (Philippines)

3.1.1 Present environmental situation:

Seven major land and water resource uses of the Agno Basin have been identified: forest exploitation, dry land agriculture, irrigated agriculture, mining, hydropower production, aquaculture and capture fisheries. They are related in simple or complex land-water relationships, and either directly affect the quality or quantity of water, or they require water as a medium.

The river basin is under stress from deforestation, resulting in heavy erosion which is further aggravated by unstable land use and improper cultivation practices. The productivity of agricultural lands in the hilly country of the upper catchment has declined by as much as 50%. The pressure on land and water resources is high, with 305 persons/km^2 in the

Pangasinan Province which extends through the major part of the Agno River. 54.2% of the total population are farmers, fishermen, hunters, loggers and related agricultural workers, exerting a high pressure on primary resources.

Mining is another important user of land. In spite of measures undertaken to prevent much of the mine waste and tailings reaching the river, a high number of mines in the catchment contribute suspended solids which, together with those from eroding lands, may reach catastrophic concentrations, especially under natural calamities such as floods caused by cyclones. Current estimate of the area adversely affected by sedimentation in the Agno River catchment is 27 000 ha of land.

3.1.2 Major engineering modifications in the basin:

These have involved structures for mining industry, especially tailings, dams and three major dams on the Agno River. In the 1950s two multipurpose dams were constructed on the middle Agno: the Ambuklao Dam and the lower downstream situated Binga Dam. They became fully operational in 1956 and 1960 respectively. A third dam, San Roque, is under construction. In 1957 a major irrigation system (ARIS) was constructed, which today irrigates 40,000 ha of land.

3.1.3 Pollution:

Mining, resulting in large input of mine tailings (26,380 t/day in 1978) into the river, together with the input of soil through erosional forces, has negatively impacted the irrigated crop yields, reducing them by 20 to 50%. This has been due to three major impacts: (i) silt accumulation from irrigation water, which causes cementing of the soils and stunts growth of crops by inhibiting root absorption; (ii) reduction of soil fertility, as indicated by low organic matter content and reduced concentrations of available phosphorus; (iii) the sediment-loaded irrigation water impeding nutrient availability and their uptake by crops.

The extent of organic pollution through sewage discharge is unknown. However, there has been an increase in fertilizer, pesticide and herbicide input into the river especially from the irrigated lands.

3.1.4 Fisheries:

The 270 km long Agno River has never been considered a fishery resource. The upper Agno is poor in fish and hardly ever fished except during the rainy season when water level is high. The two existing reservoirs have been stocked at irregular intervals with fish. Fisheries statistics are unavailable; a guesstimate gives a figure of some 500 part-time fishermen catching mostly tilapias and common carp. The reservoir fisheries is now providing about 50% of the protein requirement of the fishing families in the area.

The lower Agno with the exception of the resevoirs appears to be poor in fish. The production in the lower catchment comes from brackishwater fish ponds found mostly along the coast and in the delta of the Agno, and from a few freshwater fish ponds in the lowlands. In 1981, total production of 16,452 t of fish from 13,444 ha was achieved. Of these, 12,380 t came from brackishwater ponds. This represented 9% of the total brackish water pond production of the Philippines, and 1,200 kg/ha/yr as compared to the national average of 870 kg.

3.1.5 Fisheries planning and current activities:

Due to the abundance of marine fish stocks in the past, and more recently due to the intensification of capture fisheries in natural lakes and rapid expansion of aquaculture, virtually no attention was paid to the river capture fisheries potential of the Philippines. On the Agno, even the construction of the first two multipurpose dams in the 1950s has not attracted much attention as an environment with fisheries potential, although fish were stocked in them. A reservoir fisheries development plan was not available prior to the establishment of the new reservoirs, and there was no monitoring of catches through statistical data collection to assist in the evaluation of stocking, and to assess the level of establishment of native fish stocks in these reservoirs. No statistics were available on riverine fisheries either. Thus, with an increase in river pollution, its impact on fish stocks could not be assessed. Any planning of fisheries in the river and its reservoirs has to be therefore based on the current data collection, results from experimental catches and other approaches. The current collaborative effort of the National Power Corporation together with the Bureau of Fisheries and Aquaculture centres on pilot testing of tilapia cultures in floating cages placed in the reservoirs. A land-based hatchery-nursery complex is also being proposed. BFAR also considers undertaking the evaluation of the present fish stocks in the reservoirs, which should then form the basis for a rational stocking programme.

3.1.6 Summary of constraints to fisheries by other uses and environmental mismanagement of resources:

The constraints have been organized into a matrix relating the level of each stress to a particular type of fisheries.

The problems listed in Table 1 indicate that the upper Agno River channel is a highly stressed environment with hardly any prospects for fishery development, with the exception of aquaculture well outside the river itself. The upper course of the river has the highest sediment load and heavy metal content of the whole system. The two existing reservoirs and the third one under construction in the middle course function as a sediment trap, and although they have a multipurpose use, their fisheries potential is yet to be fully realized.

The irrigation system (ARIS) has some fisheries potential, the level of which would be controlled by the length of water retention and by sediment/mining waste and tailings inputs. Its vulnerability under the impact of sedimentation can be seen from the lowering of crop production, and fish and prawns would probably face some negative impact if introduced. Leaching of heavy metals from the deposits, and pesticide/herbicide inputs from the irrigated fields are other potential hazards. Much work is needed to harmonize the uses of mining industries, irrigated agriculture and other water uses for establishing an environment of high water quality conducive to fisheries development in the river and the irrigation system.

The reservoirs have good fisheries potential. They trap the mining and other pollutants by retention of sediments and clarification of water. Their existence also improves the downstream water quality. When the San Roque reservoir comes into existence, further improvement is expected.

The lower Agno has very little fishery, although current surveys have shown a very promising potential for Macrobrachium fisheries (Natividad 1982). At present, the top inland fish production in the basin is

Table 1

Major constraints to fisheries in the Agno Basin

Fishery Resources use		Constraints imposed on fisheries by other users								Constrains imposed by natural catastrophies	
		Large-scale deforestation of the upper catchment leading to high sediment loads	Improper agricultural practices, leading to a high sediment load	Mining waste and tailings disposal	Urban sewerage outlets	Substantial water uptake for irrigation or other uses	Regulation by damming	Heavy metals leaching from sediments	Pesticide and herbicide input from agricultural practices	Floodwater impact on mining waste/tailings storage	Floodwater wash of eroded soils
Upper Agno	Traditional fishery	H	H	H	M	H	O	H	O	H	H
	In-stream aquaculture	H	H	H	M	H	O	H	O	H	H
	Pond aquaculture	O	O	L	O	O	O	H	O	O	O
Agno River reservoirs	Capture fisheries	L	L	L	L	H	O	M	L	H	M
	Stocking	L	L	L	L	H	O	M	L	H	M
	Cage culture	L	L	L	L	H	O	M	L	H	M
Irrigation system	Stocking	M	M	M	L	O	O	M	M	H	H
	Aquaculture	M	M	M	L	O	O	M	H	H	H
Lower Agno	Capture fisheries (stream and floodplain)	M	M	M	L	M	L	L	L	M	M
	In-stream fisheries (including Macrobrachium)	M	M	H	L	M	L	L	L	M	M
	Aquculture in ponds	O	O	O	O	O	O	O	L	L	O
	Capture fisheries (estuary and delta)	M	M	M	L	O	L	L	L	L	O
Coastal	Brackish water ponds	O	O	O	O	O	O	O	L	O	O

Conflict level: H - high; M - medium; L - low; O - none brackishwater aquaculture in the lower Agno. Being outside the direct influence of the Agno River, it is not vulnerable to changes in river water quantity and quality.

To prevent further deterioration of the Agno River aquatic environment and to speed up ameliorative measures to rehabilitate the environment, more active dialogue is needed between fisheries and organizations responsible for mining, agriculture, forest exploitation, irrigational and other water uptakes and hydroelectricity production. The major objective of such a dialogue should be to achieve optimization of the land and water resources, to closely monitor the environment and to maintain a high quality of water. The size of the river basin with its complex interactions between the multitude of factors, magnified by the land-water resource development projects, shows the need to involve a more comprehensive approach than applied up to now to resolve the multitude of conflicts.

3.2 The Nam Pong (Thailand)

3.2.1 Present environmental situation:

The Nam Pong river basin, situated in a monsoonal climate, has a relatively small catchment of only 12,560 km^2. Prior to the construction of Ubolratana Dam in 1965, much of the river watershed was forested, and there was no extensive clearance for planting upland crops. The only large town in the river basin was, and still is, Khom Kae. Now, soils in the catchment above the Ubolratana Dam are highly eroded and poor in nutrients. The major tributaries to the reservoir are faecally polluted. Industrial pollution is probably negligible, as industries are mostly located downstream of the dam. The major engineering modifications in the catchment include three dams and an irrigation system. The major benefits come from the dam and power station which have been in operation since 1966, and from irrigation water uptake started in 1966. An unanticipated benefit from the project has been fish production from the reservoir.

The creation of the Nam Pong reservoir increased upland agriculture and the establishment of resettlement areas has tremendously affected the character of land use in the Nam Pong Basin. The major changes have been (i) rapid change of forest land into land for farming, (ii) change of originally flood-inundated areas into land under controlled irrigation for rice and miscellaneous crop cultivation, (iii) seasonal use of the reservoir drawdown areas for agriculture.

3.2.2 Major engineering modifications in the basin:

These include three dams: a small reservoir on the Nam Phom River, upstream of the Nam Pong reservoir, and the Nong Wai diversion dam further downstream of it. The Nam Pong (Ubolratana) reservoir, the major engineering impact on the river basin, is a multipurpose project which serves hydropower generation, irrigation, fisheries, flood control and recreation. The reservoir which covers 410 km^2 at full supply level, proved soon after impoundment to have eminent fisheries importance. The irrigation system extends on both banks of the Nam Pong River, downstream of the Nong Wai diversion dam. An industrial centre is established between the Ubolratana and Nong Wai dams, and a major town, Khon Kaen, is downstream of the Nong Wai diversion dam.

3.2.3 Fisheries:

Prior to damming the Nam Pong River, only subsistence fishery by part-time fishermen, mostly farmers, was practised in streams and rivers, lakes, canals and paddy fields. The fishing season coincided with the rainy season, and during the dry season fishing was negligible. The damming of the Nam Pong resulted in a decrease in number of fish species which were purely of riverine character. The commercial catch over the last 15 years has ranged between 30 and 63 kg/ha/yr, with the cyprinid fish dominating the total and with six major fish species forming 79.65%. With 14 fishermen/km^2 in 1978, the fishing pressure was very high, resulting in a modest average annual catch of only 340 kg/fisherman. There has been no limit on entry, no closed seasons or restricted areas to fishing. Among the 19 species of fish stocked, several were indigenous species. Of these Puntioplites proctozysron and Puntius spp. are among the six major species dominating the catch. However, insufficient data on recapture do not allow assessment of the portion of the catch derived from stocking. During the four-year period of 1969-1972 another introduced fish, sepat siam (Trichogaster pectoralis), dominated the yield.

Outside the Ubolratana reservoir aquaculture practices extended over 665 ha of ponds, 437 ha of paddy fields and 46 690 ha of other waterbodies. The Nong Wai irrigation system has a strong fisheries component with 183 fish ponds, 96 paddy fields and 16 impoundments stocked with fish. The average production of small impoundments is 300 kg/ha. The marketing to home consumption ratio differs in the Nong Wai irrigation area from that of the lakeside fisheries, with 80% of fish captured from the former being for home consumption and 20% sold and bartered, while from the reservoir 80% is sold and 20% home-consumed.

3.2.4 Cost and benefits of the river basin development:

An economic evaluation of the project published in 1981 concluded that, based on a project life of 50 years, the project provided negligible financial benefits; in other words it was a poor investment. The economic evaluation considered as costs were power, irrigation, resettlement, loss of forests and paddy fields, while benefits were power, irrigation, flood control, fishery and recreation. Social benefits including those accrued from better nutrition have not been considered.

3.2.5 Modelling for environmental management, including fisheries:

An integrated management oriented simulation model of the Nam Pong Basin, taking into account the biological, physical and socio-economic aspects of the system, was prepared in 1980 and finalized in 1981 (Mekong Secretariat, 1982), 15 years after the Nam Pong reservoir was formed. The model consists of four interacting subsystems encompassing the dynamics of water management, land-use patterns, socio-economics and reservoir fisheries. The fisheries submodel has been based on the understanding that during the last few years the reservoir fisheries have been declining. Several reasons for this have been identified, among which figures prominently lack of control of the number of fishermen, which has resulted in overexploitation and a steep decline in catch per unit effort. The fish species composition has been shifting to small herbivores of low economic value.

The reservoir fisheries submodel simulates the dynamic of the Nam Pong reservoir fisheries as a function of hydrology and fishing effort. Monthly biomass is predicted for four groups of fish, each consisting of several species: small herbivores, large herbivores, small carnivores and large carnivores. Biomass predictions are based on reservoir size, inflow, nutrients, fishing effort, predator biomass and prey availability. Fishing harvest predictions are calculated from the previous year's harvest and the current reservoir elevation.

Only those model scenarios which implemented explicit control of the number of fishermen (or limited access) predicted significant increases in fish stock and harvest and also maintained a viable population of the carnivore fish group. The most effective strategy for protection of fish stock with the aim of maintaining a high recruitment for the following year was achieved in the simulated model by reducing fishing intensity during the minimal water level period.

3.2.6 Coordination of resource management:

There has been no coordinating authority for the basin, which is the major obstacle to the realization of the potential benefits (Mekong Secretariat, 1982). At present more than 10 departments are actively engaged in developmental efforts in the Nam Pong Basin, with little or no coordination of operations. The major problems have been identified as lack of unity of command, lack of coordination in resource management, lack of qualified personnel, in particular a shortage of competent planners and project analysts responsible for development planning at the provincial level, and lack of goal consensus. Optimization of the reservoir fisheries under the multiple-use system is being coordinated by the Ubolratana Reservoir Fishery Research Centre (URFRC) which reports directly to the Department of Fisheries in Bangkok. The four major goals of the URFRC are to maintain or, if possible, to increase the fish yield from the reservoir, to protect the fish spawning grounds, to educate local people through extension programmes in conjunction with conservation projects and to use the Ubolratana reservoir to test fishery management activities for possible application to other reservoirs in Thailand (Mekong Secretariat, 1982).

3.3 The Mahaweli (Sri Lanka)

3.3.1 Present environmental situation:

Although the Mahaweli is the largest river in Sri Lanka, the total area of the basin covers only 10,420 km^2. Prior to the Accelerated Mahaweli Development Programme, initiated in 1979, the basin had a 44.5% forest cover and cash crops on 26.4%. It also had 4 000 ha of seasonal tanks, 12,800 ha of flood lakes and 9,951 ha of existing reservoirs. The current population density in the upper basin of the river is 372 persons/km^2 and that in the lower basin 88 persons/km^2; the projection for the year 2000 for the whole of Sri Lanka is 358 km^2. To provide enough food for the growing population and to increase its living standard, the Government of Sri Lanka, since independence, has given top priority to food production. This has resulted in a gradual increase of areas under cultivation, rehabilitation of the old and introduction of new irrigational facilities. The development of new lands for cultivation could only proceed at the expense of the natural habitat and its associated fauna and flora. The major changes in the environment of the basin, imposed under the present Accelerated Mahaweli Development Programme which is nearing completion, have included resettlement of people from areas to be flooded by reservoirs and transfer of elephants into new wildlife habits, including four new national parks. Large areas are to become irrigated lands.

3.3.2 Major engineering modifications:

The Mahaweli River flows through the intermediate and dry zones which, although receiving a substantial volume of rainfall during the major monsoon season, are dry for the greater part of the year. This makes the creation of irrigation facilities a prerequisite for the expansion of farming activities in these areas. Under the Accelerated Programme five major storage reservoirs are being constructed in conjunction with agricultural and related development in a 420,000 ha portion of the dry zone. When fully developed, the programme will provide settlement for nearly one million people, boost hydroelectric power output and enable achievement of self-efficiency in agricultural products. The new irrigable areas will cover 119,000 ha of land. The total surface area of the new four major reservoirs (Victoria, Randenigala, Ulhitiya and Moragahakanda) in the Mahaweli Basin will be 9,720 ha and that of Maduru Oya in the neighbouring catchment, 3,480 ha. Four dams (Victoria, Kotmale, Randenigala and Maduru Oya) will have a 477.5 MW power generation capacity.

An Accelerated Mahaweli Development Programme has been planned to be completed within 6 years. 45,000 people have already been settled from the area of Victoria Reservoir, which formed in 1984.

3.3.3 Fisheries:

Prior to the Accelerated Mahaweli Development Programme, most of the fish came from the existing reservoirs. Some fishery, mostly for shrimps, took place in the estuary, while the river itself supported largely subsistence fishery. In 1980 the reservoirs yielded 3,000 t of fish, averaging 375 kg/ha/yr. The major fish captured have been the introduced tilapia, (O. mossambicus), but the indigenous, Puntius sarana and Labeo dussumieri, have also contributed significantly to the total fish catch. The fish species are not yet in an equilibrium, as shown by an increasing importance of Hyporamphus gaimardi in fish landings from reservoirs.

Data on the fish yield for the 12,800 ha of floodplain lakes (villus) are fragmentary. The largest villus of the Mahaweli Basin yields 141 kg/ha/yr, with 65% of the catch represented by O. mossambicus. There is also seasonal fishing for Macrobrachium. It is believed that floodplain fishery could be intensified without endangering the fish stocks. Seasonal tanks have also a considerable fisheries potential.

3.3.4 Fisheries development:

During the planning for fisheries in the new reservoirs constructed under the Accelerated Programme it was predicted that for the capture fisheries a fish yield of 2,950 t/yr could be achieved. However, a detailed programme of stocking the new reservoirs will be necessary to realize the fishery potential as soon as possible. Experience from the existing reservoirs indicates that the new reservoir fish stocks would become dominated by O. mossambicus, and that stocking of O. niloticus would enhance the utilization of the high level algal production of the early post-impoundment period. The minor fish species such as cyprinids which are currently not exploited in the existing reservoirs could also be utilized. Under an inland fish farm programme, a fish breeding and research station has been established near the Ulhitiya reservoir. Fingerlings of Indian carps and two species of tilapia have been stocked, and 80 small boats have been distributed within the area. The scheme operates under a 90% subsidy from the Ministry of Fisheries.

In spite of the predicted losses of fish from floodplain fishery, there has been a net increase of a total of some 3,200 t of fish from the capture fishery in new waterbodies established under the Accelerated Programme. The total non-aquaculture fish yield from the Mahaweli and Oya basins is expected to be about 9,000 t. The seasonal tanks should provide a further 2,250 t, and aquaculture 3,750 t. The total of 15,000 t/yr should satisfy the requirements of about one million inhabitants expected to inhabit these basins in 1990.

The increasing importance of inland fish in nutrition of the people of Sri Lanka is reflected in the inclusion of a fisheries component in overall planning considerations for the Mahaweli (and Oya) river basin development. The Government has also encouraged development of aquaculture in the area.

3.3.5 Summary of constraints to fisheries:

The impact of land mismanagement in the Mahaweli Basin on the river fish has not been evaluated, perhaps because the river fish never formed an important component in nutrition of the people. Natural backwaters and existing reservoirs have been little affected by the changes in water quality and quantity as a result of the increased erosion and faster and more irregular runoff. There are no major pollutant inputs into the river system although some waterbodies are undergoing eutrophication, as evidenced, for example, by massive growth of exotic weeds such as Salvinia molesta in some reservoirs and tanks.

Environmental measures to rehabilitate the upper river catchment have involved reforestation of the highlands where large areas were destroyed by chena (slash and burn) cultivation, which in the meantime has been outlawed by the Government. Siltation is a major problem for irrigation schemes, and to reduce erosion such reforestation has been going on since 1981. As the inundation caused by damming of the Mahaweli and the Maduru Oya eliminates one-fifth of the remaining tree cover, planting of trees on a large scale will be a necessity to provide fuelwood for cooking, still used in over 90% of Sri Lankan households.

The yield of exotic tilapias which forms the basis of current fishery in existing reservoirs, as well as that of indigenous and some other introduced fish, has been found to be influenced especially by water level manipulation, predatory and fishing pressures. At present, in the two large existing reservoirs (Parakrama Samudra and Minneriya) in the Mahaweli river basin for which data are available over a 5-year period, the very high increase in fishing pressure has resulted in a significant decline in the catch per unit effort (De Silva 1985), while some other reservoirs remain underfished. In the new reservoirs, water level manipulation and fishing pressure may be expected to become major factors determining the fish yield.

4. SUMMARY AND FUTURE NEEDS

The three case studies of small river basins in humid tropical Asia have shown that in most situations inland fisheries can successfully develop under the multiple-use conditions of river basin land and water resources. Of the three basins discussed above, the Mahaweli in Sri Lanka has had engineering structures such as dams and canals in existence for a long time. Until recently the major constraint to development of fisheries in the Mahaweli was not manipulation of the water resource, but religious constraints which reduced the use of fish to a bare minimum and thus did not provide stimulus to any improvements. This has changed, however, in the second half of this century. In the other basins (Agno and Nam Pong), prior to river modifications by dams, the inland fisheries was limited to rivers and had a subsistence character.

The rapid environmental changes in river basins in the last few years, with inevitable damming of rivers, establishment of new reservoirs and irrigation systems, together with the change of people's thinking, have provided a challenge to fishery planners and managers.

The best preparatory work for rational management of new reservoirs was undertaken in Thailand where fisheries statistics have been collected since the very beginning of the Nam Pong reservoir's existence. Monitoring of the basic fisheries parameters there has helped in planning for an increase of fish yield through regular fish stocking.

In the Mahaweli Basin in Sri Lanka, exotic tilapias have proved to be the best adapted for reservoir environment, and the current fishery is largely based on them. The Accelerated Mahaweli Development Programme with its formation of several large reservoirs gives a major impetus to further development of inland fisheries, and in parallel with the large reservoirs the intensification of fisheries in small tanks and floodplain lakes is also being considered. With careful planning, followed by efficient management, the currently completed or nearly completed reservoirs, as well as the other island waters, should serve as a major example for complex river system reservoir fishery development under multiple-use conditions.

The best monitoring and statistical records available for the Nam Pong have greatly assisted in the preparation of a fishery model which alongside several non-fishery models provide further guidance for the rationalization of the Nam Pong river basin resources, including fish. Such a modelling has clearly shown that in the Ubolratana reservoir regulatory fishery mechanisms must be introduced to optimize fish yield.

With the exception of the Agno River Basin, reservoir fisheries are becoming an important source of fish protein. While the pre-reservoir period was characterized by a prevalence of subsistence fishery of a small number of fishermen, the presence of reservoirs has led to establishment of commercial fishery and to the full involvement of fisheries authorities in the reservoir fish stock improvement. A plan for the Mahaweli Basin fishery development indicates that reservoirs should contribute about 60% to the total fish production, the rest coming from tanks, floodplain lakes and aquaculture. In the Nam Pong Basin, aquaculture in ponds, paddy fields and in other waterbodies also significantly contributes to the fish protein supply. This shows that while the reservoir fishery may not be a panacea for solving fish protein requirements, it greatly contributes towards this goal.

The cost-benefit evaluation for the Nam Pong Basin, based on economic parameters only, shows only marginal benefits for investors. Social benefits, not included in the evaluation, would probably increase considerably the total benefits if a socio-economic approach were applied.

In focusing on the reservoir fishery, the well documented analysis of Nam Pong reservoir fisheries shows constraints to the fish stocks being imposed there by the fishery itself. Lack of fishery regulations have led to changes in the character of fish stocks and to their overexploitation, i.e. a tremendous increase in fishing pressure, which has led lately to a declining fish yield. Thus, it is not an impact of other users of the resource which limits the fisheries of these reservoirs. In the Agno situation where reservoirs are under the impact of mining waste, with the resulting high sediment input, it has been estimated that the reservoir fishery provides enough fish to satisfy approximately 50% of the protein demand for the subsistence fishermen community of some 500 people. The lowest (third) reservoir, nearing completion, is considered to have the best fishery development opportunities of all the reservoirs, and the fisheries authorities are now concentrating their efforts predominantly there.

The coordination of resource management is still weak in some river basins. The lack of a coordinating river basin authority for the Nam Pong Basin has been recognized as a major obstacle to the realization of the potential benefits. A similar problem is evident also for the Agno River Basin where, although collaboration between some authorities and government departments is excellent, the low level of inter-provincial contacts prevents an effective introduction of ameliorative measures.

The Mahaweli Authority, a government corporation set up in 1979, is given the responsibility for implementation of the Mahaweli Ganga Development Programme, i.e. for promoting and arranging the cooperation of government departments, state institutions, local authorities, public corporations and other persons in the planning and implementation of the scheme and in the development of any special area, e.g. fisheries.

Some of the lessons learned from the three case studies are summarized below. They show especially the need for improvement in approaches, management and coordination. The analysis of the three case studies indicates that in spite of the complexity and many interactions between various factors involved in multipurpose river basin development projects, remedial measures for optimizing fisheries under constraints are available for all situations, and it is only lack of their implementation which prevents achieving better results in river basin planning and management.

1. There is a need for better coordination between individual governmental and other bodies during the planning stage of major developments of land and water resources. The existence of a central coordinating authority has been shown to be a definitive advantage for the coordination of activities and for the implementation of the programme of development. Although government fisheries authorities have been active in all three river basins in varying degrees of efficiency, they have been weakly integrated into the overall basin development programmes. Fisheries experience gained from one river basin could be of benefit to another river basin of a similar character within the same region, and there is scope for transfer of such knowledge and experience through TCDC.

2. In the three case studies the major negative impact from users other than fisheries is from the discharge of pollutants, especially mining waste. In the Agno Basin the lack of a central authority for the basin makes enforcement of any preventive measures difficult. In such cases the government should request the enforcement of necessary remedial measures.

3. In all three basins non-reservoir associated inland fishery represents an important component of the total freshwater fish yield and highly contributes to the total fish production. This fishery utilizes floodplain lakes and tanks (Mahaweli), brackishwater ponds (Agno), and ponds and irrigation systems (Nam Pong). Fisheries development planners consider fish production from these waterbodies equally important as that from the reservoirs.

4. In all three basins a sound managerial approach to inland fisheries, both capture and culture, requires a good understanding of the current environmental situation, which should be based on regular data

collection. Regular monitoring of selected limnological parameters, fish stocks and fishing effort should be introduced where still lacking, and improved where effort on such data collection is not consistent. This would enable one to more carefully estimate the impact on fishery by other uses of the same resource than is possible at present.

5. In two river basins, i.e. Nam Pong and Mahaweli, excessive fishery pressure on reservoir fish stocks has resulted in declining yield. A model constructed for the Nam Pong (Ubolratana) reservoir fisheries in Thailand shows that the major constraints imposed on the fisheries in the multiple-use context are those originating from the fisheries itself. Similar models for the other two basins would greatly assist in clarifying the level of impacts and would help to identify remedial measures for fisheries improvement. As such models have to be based on sound data, the establishment of careful data collection is a prerequisite for the modelling process.

6. Amongst factors most closely related to the reservoir fish yield are (i) fishing pressure (Nam Pong and Mahaweli): the fish stock composition has been shown to change unfavourably as a result of heavy fishing pressure under the situation of non-regulated fishery (Nam Pong), while a better regulation is wanting in the Mahaweli; (ii) engineering manipulation of water level (Mahaweli); (iii) the presence or absence of exotic fish (Mahaweli); (iv) stocking (Nam Pong, Mahaweli).

7. The selection of the most suitable fish species for reservoir stocking is still limited by our poor knowledge of species interactions. While exotic species introductions into some reservoirs may result in a long-term success in the form of their dominating fish landings, e.g. tilapias in the Mahaweli, elsewhere the success may be only temporary, e.g. Trichogaster pectoralis in Nam Pong. Long-term observations in the Nam Pong reservoir have shown that indigenous fish figure more prominently in fish landings than exotic fish.

8. There is a need for guidelines for technical advice on optimizing inland fisheries in multiple-use context. The use of such guidelines during the preparatory stages, i.e. during the planning and design process when negotiations between the future users take place, would assist both the fisheries and non-fisheries planners in a better understanding of specific requirements of fisheries in regulated waters and in otherwise modified conditions. In turn, this should promote the appreciation of fisheries needs and interests under new situations resulting from other impacts.

9. The case studies have shown the need for a manual on suitable fish species for stocking Indo-Pacific inland waters, especially reservoirs and lakes. Such a manual should summarize the current experience with each species under various reservoir and aquaculture conditions, and to show its suitability for multispecies situations.

10. The only available evaluation of cost/benefit ratios for the Nam Pong river basin development is based on economic parameters only. Although it is widely recognized that fisheries have contributed considerably towards the favourable opinion about the success of the reservoir component of the scheme, in economic terms the total Nam Pong river basin development has been considered only marginally successful. It is recommended that social aspects be included in future cost/benefit evaluations of multiple-use projects.

5. REFERENCES

De Silva, S.S., Status of the introduced cichlid Sarotherodon mossambicus (Peters) in the reservoir fishery of Sri Lanka: a management strategy and ecological implications. Aquacult.Fish.Manage., 1:91-102 (in press)

Mekong Secretariat, Nam Pong Environmental Management Research project. 1982 A project supported by the Ford Foundation. Final report for Phase III. Part L: An integrated simulation model for resource management. Bangkok, Interim Committee for Coordination of Investigations for the Lower Mekong Basin (Lao People's Democratic Republic, Kingdom of Thailand and Socialist Republic of Vietnam) April 1982, MKG/101:311 p.

Natividad, J.M., Hydrobiological characteristics of some Philippine river 1982 systems which are natural habitats of Macrobrachium species. In Giant prawn farming, edited by M.B. New. Amsterdam, Elsevier, Developments in aquaculture and fisheries science, 10:31-54

A. THE AGNO BASIN (THE PHILIPPINES)

by

Elvira A. Baluyut
Inland Resources Development Corporation
Suite 111 Mercantile Insurance Building
Gen.Luna cor.Beaterio Street
Intramuros, Manila
Philippines

ABSTRACT

The Agno River Basin in Luzon in the Philippines has been under considerable stress from development activities. The upper catchment has been exposed to drastic and rapid deforestation and to extensive mining, both leading to heavy erosion, high sediment load in the Agno River and siltation. In the lower basin, two dams have been constructed for hydropower and irrigation purposes, both of them functioning also as sediment traps. Sediment and heavy metal input through the irrigation system has lowered the soil quality with a resulting negative impact on agriculture of lowland plains. Fish stocks of the upper Agno have never been of commercial significance, but some subsistence fishing has been carried out in the lower Agno, especially during floods. The two reservoirs constructed on the Agno in the 1950s have good fisheries potential but, so far, there has been only a minimal effort spent on their fisheries development. Aquaculture has been the major fish producer in the Agno River Basin, with 16,452 mt (in 1982), of which 12,380 mt came from brackishwater ponds. Brackishwater pond aquaculture of the Agno River Basin contributed 9% of the total brackishwater pond production of the Philippines, with 1,200 kg/ha/yr, as compared with the national average of 870 kg/ha/yr.

Current efforts of government agencies aim at developing fisheries in the Binga and Ambuklao reservoirs, with proposals to construct a new land-based hatchery-nursery complex to provide fingerlings of selected fish for regular reservoir stocking, and to set up a floating cage culture. In spite of that, the brackishwater aquaculture will probably continue to greatly dominate the inland water fish production in the Agno River Basin.

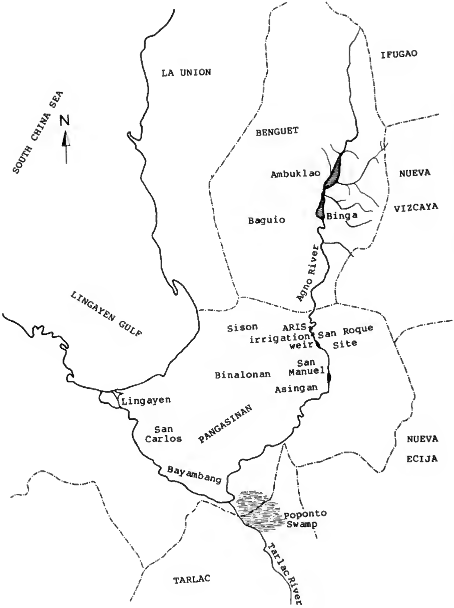


Figure 1. The Agno River Basin.

1. INTRODUCTION

The rush towards economic development by way of resource exploitation, often without regard for the environment, has left numerous ecological systems in a state of disarray. Man, in his desire to obtain direct and readily measurable economic gains, has neglected to concern himself with the indirect, longer-term benefits that he stands to lose as a consequence of environmental deterioration.

As a result, his multitudinous activities on land and in water have caused different degrees of interference with the ecosystem. In the watersheds, his manifold economic and development pursuits have led to habitat deterioration, making him the greatest single biogenic factor affecting water quality, both directly, as a result of discharges into rivers, and indirectly, through his activities on land (Petr, 1983).

In Southeast Asia, as in the other developing parts of the world, the situation is more serious on account of the pressures arising from rapidly expanding populations - a situation that makes choices more urgent and decisions often made without a full understanding of either options or optimality (Hanson and Koesoebiono, 1977). The price of development in the region has therefore been frequently irreparable damage to the environment, brought about by indiscriminate deforestation, industrialization, and urbanization.

In the Agno River Basin in the Philippines, for example, the productivity of agricultural lands has declined by as much as 50%, and the riverine fish have been almost eliminated as a result of excessive siltation caused by extensive deforestation and the discharge of mine tailings by large mining companies in the watershed.

Experiences like these strongly suggest the need to adopt an integrated resource management strategy that seeks to maximize potential socio-economic benefits while minimizing possible ecological damage. For, while it is true that "economic development has been given the force of a moral imperative, the resources of the entire world must be developed rationally to achieve the highest quality of living for mankind" (Dasmann et al., 1973). This implies the need to shift emphasis from purely economic goals to those that take into careful consideration the natural processes and resources that may need to be sacrificed in the course of reaching such goals.

It is in this light that the integrated, multi-use approach to area development assumes greater significance. In contrast to old methods which focused on single projects in isolation from others that may be planned for the same area, the integrated approach calls for a coordinated and harmonious development of various works in relation to all resonable possibilities of the basin (UN, 1970). In addition, development planning of this type takes into account various environmental factors or ecological issues ranging from the immediate, very specific, and readily predictable to the less specific, less easily discerned, long-term, and possibly unforeseeable (Dasmann et al., 1973).

While the integrated, multipurpose development of river basins is generally considered superior to the single-use approach, mention must also be made of the possibility of conflicting resource uses and the need to minimize, if not totally resolve, these conflicts. It is also quite sad to note that from among a whole spectrum of resources within a river basin, fisheries is often relegated to a low priority or is not given any priority at all.

In some instances, it is only after the project is completed that some thought is given to the fisheries component - either because it has performed so well that its gains surpass the projected primary benefits, or bcause the project managers realize all of a sudden that the large volume of water in the reservoir may just as well be used for fisheries.

It is with this background in mind that this case study of the Agno River Basin is written. This paper considers the Agno River Basin System with its socio-economic, physical, and biological resources, and the major past and present development projects. It discusses issues and problems arising from river basin development as they relate to the fisheries and the environment.

2. PROFILE OF THE AGNO RIVER ECOSYSTEM

The Agno River Basin is one of the two major basins in Central Luzon. It lies within 120°00' and 121°00'E and 15°00' and 16°45'N, covering an area of 13,800 km^2 (Fig. 1). The Agno River with its tributaries, drains several provinces, but the major part of its catchment is situated in the Pangasinan Province. In this Province the largest municipalities are distributed mainly along the national roads and the central and eastern parts of the Province. They are lowland rice-producing areas.

2.1 Social environment

2.1.1 Population and related features:

Pangasinan Province had the third largest population count in the Philippines at 1.636 million in 1980 (NEDA, 1982). This figure represents 46% of the regional total and 3% of the national total. The population of the Province showed a 7% growth rate over the five-year period from 1975 to 1980, equivalent to an average annual growth rate of 1.4%. Population density in 1980 was 304.8 persons/km^2, the highest in Region I which covers the Northwest of Luzon (Table 1).

The 1975 provincial statistics placed the total labour force (15-64 age group) of the Province at 1,647, of which 81% or 862,267 come from the rural sector. Classified by major gainful occupation, 54.2% were farmers, fishermen, hunters, loggers, and related agricultural workers; 12.3% were craftsmen, production process workers; 8% sales workers; 6.6% engaged in services; and 6% in technical and related activities.

Approximately 70% of the provincial households are classified as least developed in terms of family incomes, high rate of unemployment, inadequate accessibility to social services, and infrastructural facilities.

A high level of malnutrition exists in the Province. Of 116,394 pre-school children surveyed in 1980, 41.5% had first degree malnutrition; 29.4%, second degree; and 5.8%, third degree (NACIAD et al., 1981).

In some parts of the Province, quality of water is unsatisfactory, resulting in problems of gastro-enteritis and other water-borne diseases. In many barangays (villages), the potable water supply is inadequate for the requirements of the communities. The water systems are fast deteriorating and are not being expanded at a rate sufficient to meet population growth. To compound the problem, there are no organized refuse collection and disposal facilities, except in a few cities and poblacions, the most common methods of waste disposal being composting, burning, and open dumping.

Table 1

Population density of Pangasinan as compared to the other provinces of Region I of Luzon Island (from NEDA, 1982)

	Population (in thousands)		Land area (sq. km)	Density (persons/sq.km)	
	1980	1975		1980	1975
REGION I	3,541	3,269	21,568.4	164.2	151.6
Abra	160	147	3,975.5	40.3	37.0
Benguet	355	302	2,655.4	113.6	113.8
Ilocos Norte	391	372	3,399.3	114.9	109.4
Ilocos Sur	444	420	2,579.6	172.0	162.7
La Union	452	415	1,493.1	303.1	277.7
Mt. Province	103	94	2,097.3	49.1	44.9
Pangasinan	1,636	1,520	5,368.2	304.8	283.2

The literacy level of the Province is 81.4% and educational facilities are adequate. There are 908 complete elementary schools, 271 secondary schools, and 35 institutes of higher learning.

2.1.2 Agriculture and industry:

The primary base of the economy of the Province is agriculture, the population of Pangasinan being predominantly rural. Most agricultural activity is done in the central part of the Province where the area is mostly lowland and partly under irrigation. Portions of the eastern and western parts of the Province are also planted to rice, corn, vegetables, and fruit trees. Pangasinan is considered one of the major rice-exporting provinces. In 1980, while productivity per unit area increased, the total area devoted to rice decreased to 235,000 hectares primarily as a result of the conversion of rainfed areas to fruit orchards, expansion of residential areas, and erosion. Likewise, the actual irrigated areas decreased from 133,572 hectares in 1976 to only 78,155 hectares in 1980, largely due to the siltation of irrigation canals and lack of proper canal maintenance (NACIAD et al., 1981). Serious problems have arisen from the upstream mine tailings which are at present discharged into the river and silt up the canal systems. This has prevented the expansion of the present irrigation systems and has consequently limited the possibility of expanding the present agricultural areas.

Due to the constraints to agricultural production it is predicted that the Province shall be gradually shifting from an agriculture-based economy to an industry-based one. The National Water Resources Council (NWRC) (1983) projects that the industrial sector will grow at a much higher rate, from about 26% in 1975 to 50% in the year 2000. Agriculture is then expected to drop from a share of 46% in 1975 to 30% in 2000.

2.2 Physical environment

2.2.1 Topography:

The Agno River is about 270 km in length from its source in the Cordillera mountains to its mouth in the Lingayen Gulf. It drains the southeastern half of the Central Cordillera in Benguet Province, flows across the broad Pangasinan Plain, and enters the Lingayen Gulf. Stream gradients are steep in the upper reaches and flatten appreciably downstream from San Manuel, from where the river flows south to Tayug, veers off to the southwest through Rosales, and into the Poponto Swamps, (also known as Mangabol Marsh), where it is joined by the Tarlac River. From the Poponto Swamps, the flow becomes northwestward, skirting the eastern slope of the Zambales Mountains and finally discharging into the Lingayen Gulf.

The Cordillera Central, from which the Agno River rises, is geologically a young mountain range with very pronounced erosion phenomena and a morphology characterized by steep slopes and narrow gorges. Faults, some of regional importance, tend to promote and concentrate erosion phenomena. Erosion has considerably increased as a result of recent deforestation and is still continuing at a high rate. Deforestation has progressed to the extent that primary forest has almost disappeared, except at some spots above elevation 800 m. The practice of setting fire to the grassed slopes at the end of every dry season serves only to increase the effect of deforestation (ELC et al., 1979).

The lowland plain is filled in by sediments carried by rivers and deposited in fans and bars. This sedimentation process tends to isolate low areas between relatively higher levels so that a large portion of the Pangasinan plain suffers from inadequate drainage and flooding, particularly in the lower part of the Agno River plain.

The river is torrential, high sediment transport capacity in the mountains, and meandering and sharply reduced flow velocity and sediment transport in the plains.

2.2.2 Meteorology:

The climate of the Agno River Basin is characterized by two seasons: a dry period from November to April, and a wet period during the rest of the year.

The mean annual rainfall is about 3,300 mm (Fig.2). The maximum annual precipitation of 9,038 mm was recorded at the Baguio City station in 1911 and is the highest ever recorded for the Philippines. The area of lowest precipitation is along the river valley upstream of Binga where rainfall averages about 2,000 mm/yr. Throughout the year, precipitation varies sharply between the dry season when zero rainfall can occur over two or more consecutive months, and the wet season when practically the entire annual rainfall occurs. The rainiest period is the four months span between June and September, when about 70 to 80% of the annual rainfall occurs.

Differences of several degrees in mean annual air temperature occur between mountain and river valley sites, with the mean temperature in Baguio City (altitude 1,500 m) being 19.2°C and that in Dagupan City at sea level being 27.7°C. In the Agno Valley, at Ambuklao (altitude 900 m), mean annual temperature is about 25°C.

2.2.3 Soils:

The soils in the Basin area represent a wide range of development stages - from young soils of recent alluvial deposits to old soils in the mountainous areas of the northeastern section. Soil textures range from moderately coarse to fine.

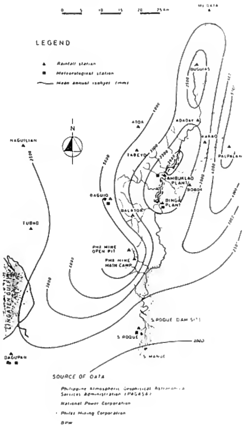


Figure 2. Isohyetal map of rainfall (in mm) (from ELC et al., 1979)

Several soil series and land types have been established by the Bureau of Soils. The San Manuel series, which occurs mainly on the extensive alluvial plain, is characterized as deep and poorly drained to moderately well-drained. It has moderate natural fertility and is medium to low in organic matter content. Surface soil reaction is medium acidic and permeability is moderate, with medium water capacity.

The San Fabian group is predominantly clay-loam with hardpan subsoil and generally underlain by volcanic tuff. The Alaminos group in the upland and rolling hills are predominantly loam and are susceptible to erosion. The last group is composed of soils which are developed on the sedimentary rocks, generally on limestone.

Soil quality in the Province is mainly low to moderate, with 53% of the total area of low fertility and 31% of moderate fertility. Also, about 14.2% of the soil in the Province is highly susceptible to erosion and 21.4% is moderately susceptible to erosion. The National Environmental Protection Council (NEPC) and the National Council on Integrated Area Development (NACIAD), in a joint report on the Ecological Profile of Pangasinan (1983), attribute the high percentage of low to moderate soil quality and the erosion susceptibility to the extensive deforestation/ denudation of the watershed leading to siltation, deposition of mine tailings, unstable land use, and improper cultivation practices.

2.2.4 Surface water:

2.2.4.1 River discharges and floods:

In the Pangasinan Province, the Agno River and its tributaries are the main sources of surface water in the Province for use in irrigation and for inland fisheries (Table 2).

The discharges of the Agno River basically follow the rainfall cycle over the Basin, the low period being from January to May and the high flows in the remaining months, with the highest from July to October when the cumulated discharge is more than 70% of the annual volume (Fig. 3).

The floodplain of the Agno River lies in the northeastern portion of the Basin and covers 1,810 km^2. Directly affected by floods are 27 municipalities involving population of more than 800,000 (based on 1975 census). During the wet season the Agno River and its tributaries overflow their banks and flood adjacent lowlands, usually causing extensive damages to life and property. Also, unguided development on the floodplain, reduced conveyance capacities of waterways due to excessive sediment load, and river meanders that destroy valuable chunks of land adjacent to the river banks further aggravate the flood situation in the Basin.

An ecological survey of flood risk areas by the NEPC and NACIAD (1983) showed three types of flood-prone areas: 1) areas near the headwaters of Agno River as it approaches the flat alluvial plains of Pangasinan; 2) areas situated near the banks or included in the river's drainage; and 3) areas on the coast, especially those affected by the tributaries of the Agno as it changes its course and enters the sea.

2.2.4.2 Water quality:

Ecological mapping for water quality shows that about 5.2% of the total land area of the Province has a very high pollution level. About 2.3% is heavily polluted with a severe impact on aquatic life; about 8.3% moderately polluted with tangible impacts on aquatic life; 33.6% slightly polluted; and the remaining 50.6% is relatively undisturbed. The extremely

Table 2

Discharge data for rivers of the Pangasinan Province
(from NACIAD *et al*., 1981)

Name of River	Location Gauging Station	Drainage Area (hectares)	Discharge Rate	(m^3/sec)	
			Min.	Max.	Ave.
Agno	San Roque, San Manuel	122,500	8.02	2,373	78.53
Agno	Carmen, Rosales	220,900	8.00	4,330	123.62
Agno	Bayambang	228,400	8.30	910	92.37
Agno	Wawa, Bayambang	419,000	8.60	14	9.29
Agno	Urbiztondo	513,400	10.46	1,914	124.19
Taga Musing	San Manuel	5,300	0.32	175	3.47
Ambayoan	San Manuel	11,600	1.75	461	15.92
Balingcaging	Agno	14,500	0.13	988	15.86
Banila	Umingan	14,800	0.07	860	10.83
Bayaoas	Mangatarem	6,400	0.32	168	-
Pila	Mangatarem	12,600	0.20	398	6.45

Table 3

Classification of fresh surface waters and
recommended best usage (from NPCC, undated)

Classification	Best usage
AA	Source of public water supply
A	Source of water supply that will require complete treatment
C	Propagation and growth of fish and aquatic resources
D	Agriculture, irrigation, livestock, watering, and industrial use
E	Navigational use

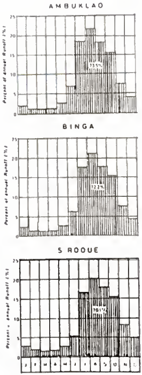


Figure 3. Monthly runoff in the Agno River Basin shown as percentages of the annual runoff (from ELC et al., 1979)

polluted areas, which are mostly heavily silted farmlands, are concentrated in the northeastern part of the Province. Those areas traversed by the Agno River are all moderately polluted.

Based on the river classification of the National Pollution Control Commission (NPCC), the waters of the upper Agno are classified as Class A while the lower Agno is Class C (Table 3). The upper Agno is used for domestic water supply, irrigation, bathing, and power production and the lower Agno for fisheries and irrigation.

In the past decade or so, however, the Agno River has been receiving significant loads of sediments coming from erosion of natural slopes and from several mines operating at the upper reaches. The river water has been shown to be contaminated with toxic metals such as iron, copper, zinc, lead, and mercury at levels exceeding permissible limits for indigenous fish species like carp, tilapia, and milkfish (Table 4). Also, the water immediately offshore of Lingayen Gulf shows the presence of noxious heavy metals in concentrations considerably above any acceptable standard (Table 5). These are at least partially attributable to contaminants flowing through the Agno River system (NACIAD et al., 1981).

2.2.5 Ground water:

Ground water is the main water source for household consumption and is used by a small number of farmers for irrigation. The main aquifer consists of sand, gravel, and silt, and is recharged by rainfall in the Sierra Madre range and through numerous creeks and streams. Not much is known of the quality of groundwater resources in the Basin. The NEPC/NACIAD (1983) Report on Pangasinan states that based on aquifer transmissivity and soil permeability, ground water in Pangasinan is, for the most part, of high quality except for very small patches of problem areas, such as in Dagupan City (for inferior bacteriological quality) and in the coastal fringes of Agno, Bolinao, and Alaminos where salt water intrusion has been observed.

In Dagupan City, a high incidence of gastroenteritic diseases, with a five-year average morbidity of 439/100,000 population (representing 32% of communicable disease deaths) has been reported (NACIAD et al., 1981). These may have been due to the high soil permeability and high pollution levels of surface water bodies in the Dagupan estuary, particularly in the immediate city area and in the mid-reaches of all tributaries of the Malabago-Sinocalan system, which may have resulted in the contamination of groundwater supplies, especially for drinking water.

2.3 Fisheries resources of the Agno River Basin

Apart from agriculture, marine and inland fisheries constitute another major economic activity in the Province. Pangasinan is a coastal province, the length of its coastal area extending along the Lingayen Gulf from San Fabian in the north to Infanta in the south. Other important coastal fishing grounds in the province are Tambac Bay, Dasol Bay, China Sea, and Sual Cove. Fourteen municipalities covering 129 barangays are classified as coastal.

The Province is also endowed with inland waters like the Agno River, the Mangabol Marsh, Mabulitec Marsh, and Bued River, among others. The Agno River is considered the longest river in the Province, originating from Benguet and flowing into Lingayen Gulf, cutting through sixteen municipalities on both sides.

Table 4

Levels of toxic metals (ppm) in the Agno River Basin (NACIAD et al., 1981)

	Upper Agno	ARIS Intake	Sediments in ARIS canals and fields
Iron (Fe)	3.5-17	0.9-3.1	14,500-39,000
Copper (Cu)	0.08-3.5	bdl-8.9	146-997
Zinc (Zn)	0.08-5.1	0.03-0.08	32-133
Lead (Pb)	0.13-1.6	0.09-0.13	9-47
Manganese (Mn)	0.63-4.05	bdl-0.01	-
Cadmium (Cd)	bdl-0.04	bdl	0.61-1.24
Nickel (Ni)	bdl-0.04	bdl	-
Silver (Sg)	bdl-0.03	bdl	-
Mercury (Hg),ppb	0.2-0.4	bdl-0.9	0.02-0.05
Cyanide (Cn)	6.0-11.2	-	-
Sulfates	200-500	157-326	-
Suspended solids	330-500	7.7-8.1	-
pH	7.1-8.1	7.7-8.1	-

Notes: ARIS = Agno River Irrigation System
bdl = below detectable limit
NPCC recommended safe levels for fish:
Iron: 0.095 ppm for carp and tilapia
Manganese: 0.007 ppm for carp and tilapia and milkfish
Nickel: 0.054 ppm for carp and tilapia

Table 5

Values of noxious metals in waters off Lingayen Gulf (from ELC et al., 1979)

	Concentration (ppm)		
Metal	Lingayen Gulf	NPCC standards*	Japanese standards**
Hg	0.07	0.08	0.0005
Cd	1.00	0.20	0.01
Pb	0.00002	0.10	0.10

* Maximum allowable concentration for fish

** Guidelines for acceptable environmental quality of water

2.3.1 Marine fisheries:

About 15,000 fishermen derive their livelihood from marine fishing, with the following groups of fishes being the most common: groupers, snappers, mullets, goatfishes, sardines, swordfishes, roundscads, tuna, and mackerel (BFAR, 1981). In 1981, total marine fishery production from the Lingayen Gulf was 19,449 mt, of which 7,692 mt came from commercial fishing and 11,757 mt from municipal fishing (Table 6). Of the various fish groups, the most abundant were those that belong to the ISCAAP Group No. 36 (mackerels, tunas, bonitos and billfishes), followed by the jacks, scads, mullets, and garfish (ISCAAP No.34), and the perches, breams, snappers, and eels (ISCAAP No.33).

Table 6

Marine fishery production (mt) from the
Lingayen Gulf, 1981 (from BFAR, 1981)

ISCAAP Group No.	Fish Group	Grand Total	Commercial Fishing*	Municipal Fishing**
Lingayen Gulf Marine Fishery		19,449	7,692	11,757
24	Shads, milkfish	64	-	64
31	Flounders, halibuts	20	15	5
33	Perches, breams, snappers, eels	3,125	637	2,488
34	Jacks, scads, mullets, garfish	3,450	821	2,629
35	Herrings, sardines, anchovies, etc.	1,900	74	1,826
36	Spanish mackerels, tunas, bonitos, billfishes	8,856	5,755	3,101
37	Mackerel, hairtails	640	250	390
38	Sharks, rays	161	-	161
39	Misc.marine fishes	98	97	1
42	Crabs	61	-	
43	Lobsters	24	-	24
45	Shrimps/prawns	326	13	313
47	Misc.marine crustacea	1	-	1
56	Clams, cockles, shells	10	-	10
57	Squids, octopus, cuttlefish	713	30	683

* Commercial fishing is done using a licensed vessel over three gross tons in weight and operating in areas more than seven fathoms deep.

** Municipal fishing uses vessels three gross tons or below and operates in areas less than seven fathoms deep.

ISCAAP - International Statistical Standard Classification of Aquatic Animals and Plants.

ISCAAP Group- includes species of fish belonging to the same group and sub-class.

2.3.2 Inland fisheries:

2.3.2.1 Riverine fisheries:

From limited information available on the fisheries of the Agno River itself, it is evident that the river has not supported a commercial fishery since fishes in it are rare. The fishermen along the banks are only part-time fishermen who fish when the river water is high, as in the rainy season (Gracia and Natividad, 1979). In a recent survey conducted by the BFAR in August 1983, it was noted that the lower Agno is not exploited anymore since there are no fish to catch (Gracia and Magsumbol, 1983).

In 1979, experimental fishing by the BFAR showed that the dominant fishes in the river are the mullets (_Mugil_ sp.), common carp (_Cyprinus carpio_), tilapia and mudfish (_Channa striata_) (Table 7). Other minor fishery resources include freshwater shrimps (_Macrobrachium_ sp.), snails, and crabs, which were abundant in areas in Lingayen, Bugallon, and Urbiztondo, where the river had muddy bottoms (Gracia and Natividad, 1979).

Table 7

Major fish of the Agno River, based on experimental fishing (Gracia and Natividad, 1979)

Fish species	Percentage composition	Ave. length (cm)	Ave. weight (gm)
Mullets	39.1	14.1	33.9
Common carp	34.5	12.8	113.2
Tilapia	19.1	11.7	70.7
Mudfish	7.3	21.6	230.5

2.3.2.2 Fish ponds:

The production from the inland fisheries sector comes mainly from brackishwater fish ponds, found mostly along the coast and in the delta of the Agno River, and from a few freshwater fish ponds in the lowlands. The brackishwater fish ponds are mostly privately owned, with the biggest number found in the municipalities of Binmaley, Lingayen, and Bani (Table 8). The biggest total hectarages of fish ponds are found in Binmaley, Bolinao and Anda (Table 9). Their size distribution by number of farms and by hectarage is shown in Figure 4.

In 1981, a total production of 16,452 mt of fish was obtained from 13,444 hectares of fish ponds (both brackishwater and freshwater) in the Province (Table 10). The total brackishwater fish production of 12,380 mt accounts for about 95% of the total production of Region I and about 9% of the total brackishwater pond production of the Philippines in 1981. About two-thirds of this production is supplied by the municipalities of Binmaley and Lingayen, where the fish ponds rely on the Agno River for their water supply (Gracia and Natividad, 1979). It is interesting to note that on a per hectare basis, the average production of brackishwater fish ponds in Pangasinan, which is equal to 1,200 kg/ha/yr, is higher than the national average of 870 kg/ha/yr.

Table 8

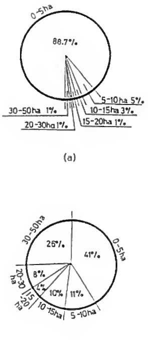
Size distribution of brackishwater fish ponds in Pangasinan by number of ponds (from GOPA, 1981)

Municipality	0-5 ha		5-10 ha		10-15 ha		15-20 ha		20-30 ha		30-40 ha		40-50 ha		50 ha		Total	
	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Agno	100	(27)															100	(27)
Alaminos	62	(73)	11	(13)	15	(17)	4	(5)	7	(8)							100	(117)
Anda	39	(34)	13	(11)	31	(27)	1	(1)	7	(6)	3.5	(3)	4.5	(4)	1	(1)	100	(87)
Bani	71	(225)	9	(28)	6	(19)	3	(10)	5	(16)	2.5	(8)	1	(2)	2.5	(8)	100	(316)
Binmaley	99	(980)	0.5	(4)													99	(984)
Bolinao	76	(108)	11	(15)	4	(6)			6	(8)	1	(1)	1	(2)	1	(2)	100	(142)
Bugallon	96	(165)	4	(7)													100	(172)
Dagupan	68	(152)	24	(52)	5	(10)	2	(4)	0.5	(1)	1	(3)					100	(222)
Dasol	83	(66)	6	(5)	5	(4)			1	(1)	1	(1)	4	(3)			100	(80)
Infanta	83	(29)	3	(1)	14	(5)											100	(35)
Labrador	99	(111)	1	(1)													100	(112)
Lingayen	93	(510)	4	(23)	2	(12)	0.5	(3)	0.2	(1)							100	(549)
Mangaldan	94	(132)	3	(4)	3	(4)											100	(140)
San Carlos	99	(111)							1	(1)							100	(112)
San Fabian	100	(65)															100	(65)
Sual	90	(17)					5	(1)					5	(1)			100	(19)
TOTAL	88.7	(2805)	5	(164)	3	(104)	1	(24)	1	(42)	0.5	(16)	0.4	(12)	0.4	(12)	100	(3179)

Table 9

Size distribution of fish ponds in Pangasinan by hectarages (from GOPA, 1983)

Municipality	0-5 ha		5-10 ha		10-15 ha		15-20 ha		20-30 ha		30-40 ha		40-50 ha		50 ha		Total	
	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Agno	100	(34)															100	(34)
Alaminos	14	(116)	16	(127)	23	(184)	15	(120)			9	(66)			25	(203)	100	(816)
Anda	19	(387)	21	(414)	8	(155)	4	(81)	6	(122)	9	(171)	14	(289)	19	(384)	100	(2003)
Bani	12	(116)	10	(101)	35	(339)	5	(48)	17	(165)	13	(133)	8	(77)			100	(979)
Binmaley	20	(507)	8	(194)	6	(141)	7	(180)	12	(297)	8	(190)	2	(64)	37	(932)	100	(2505)
Bolinao	73	(1722)	5	(109)	3	(67)			4	(100)	3	(71)	3	(85)	9	(211)	100	(2365)
Bugallon	23	(125)	10	(55)	6	(36)			26	(141)			11	(60)	24	(135)	100	(552)
Dagupan	84	(282)	11	(39)	5	(17)											100	(338)
Dasol	31	(135)	10	(43)	13	(55)			8	(32)	11	(48)	28	(121)			100	(434)
Infanta	36	(74)	16	(34)	34	(71)			14	(29)							100	(208)
Labrador	94	(163)	6	(11)													100	(174)
Lingayen	66	(783)	14	(164)	13	(151)	4	(43)	3	(37)							100	(1178)
Mangaldan	74	(245)	9	(29)	17	(54)											100	(328)
San Carlos	84	(177)							16	(32)							100	(209)
San Fabian	76	(135)	7	(14)					17	(29)							100	(178)
Sual	35	(27)					69	(51)									100	(78)
TOTAL	41	(5028)	11	(1334)	10	(1270)	4	(532)	8	(984)	5	(679)	6	(696)	15	(1865)	100	(12379)



(a)

(b)

Figure 4. Size distribution of fishponds in Pangasinan by (a) number of farms and (b) by hectarage, (from GOPA, 1983)

Table 11

Production from brackishwater and freshwater fishponds in operation in 1981 (BFAR, 1981)

	BRACKISHWATER						FRESHWATER		[illegible]	
	AREA (ha)		PRODUCTION (mt)		TOTAL					
	Privately owned	Govt. leased	Privately owned	Govt. leased	Area (ha)	Production (m t)	Area (ha)	Production (m t)	[illegible]	[illegible]
PHILIPPINES	99 697	96 135	103 875	66 556	195 832	170 431	12 289	10 616	208 1[illegible]	[illegible]
Region 1	10 838	2 571	12 609	3 070	13 409	15 679	[illegible]	1 868	[illegible]	[illegible]
Pangasinan	9 857	2 523	11 828	3 028	12 380	14 856	1 064	596	[illegible]	[illegible]

Of the volume of fish produced in the Province, however, only about 50% is consumed locally. The rest is sold mainly in the markets of northern Luzon and about 2% in Metro Manila (Fig. 5) (GOPA, 1983).

3. AGNO RIVER BASIN DEVELOPMENT: PAST AND PRESENT

Since the early 1950s, the waters of the Agno River have been harnessed for electricity and irrigation - the Agno River being the first river in the Philippines to be dammed for hydropower production. The

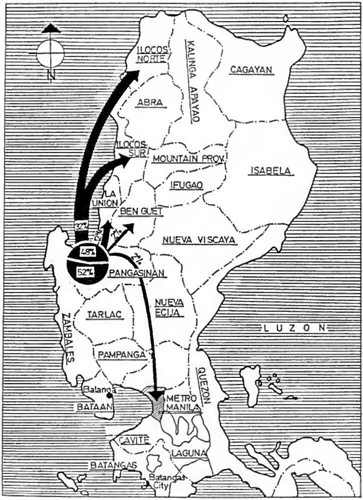


Figure 5. Distribution of the fish produced in Pangasinan (from GOPA, 1983)

Ambuklao and Binga projects in the upper Agno River, fully operational in 1956 and 1960, respectively, have since then provided electric power to the province of Pangasinan and most of Central Luzon. The Agno River Irrigatin System (ARIS), built in 1957, uses Agno River water to irrigate some 40,000 hectares of agricultural lands in the Province.

Continuing extractive activities in the watershed, however, have now put these projects in serious jeopardy. Logging, deforestation, shifting cultivation, and mining in the upper Agno district, have severely affected the Binga and Ambuklao reservoirs and the ARIS. At this point in time, a solution to the siltation problem in the Basin is sought in the construction of the San Roque Multipurpose Dam in the lower Agno. Apart from that, a number of proposed short-term and long-range ameliorative measures is designed to be undertaken to alleviate the present situation.

3.1 The Binga and Ambuklao dams

3.1.1 Physical features:

Both dams are located in the upper reaches of the Agno River, in Benguet Province, within 19 km of each other (Fig. 6). Ambuklao Dam is located in the elevated areas of the municipality of Bokod, about 36 km

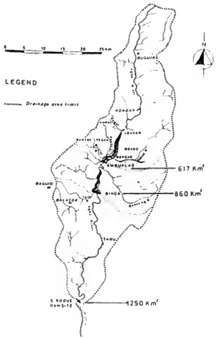


Figure 6. Binga and Ambuklao reservoirs and the proposed San Roque Dam. Also shown are their respective drainage areas. (From ELC et al., 1979)

northeast of Baguio City. Binga Dam is in the municipality of Itogon, 19 km downstream of Ambuklao, and retains water spilled from Ambuklao.

The Ambuklao reservoir is supplied by five tributaries: Lalay and Bantay Rivers in the west and northwest, Pesick River in the north, and Agno and Bokod Rivers in the northwest and east (Fig. 7). It is also a 617 km^2 watershed which is largely devoid of trees. The reservoir has a maximum surface area of 750 hectares at the highest water level and a maximum depth of 124 m. The dam has an installed capacity of 75 MW, and supplies electricity to Central Luzon.

The Binga Dam, also known as Agno River Project No.2, has a capacity of 100 MW and supplies Central and Southern Luzon. The reservoir has a maximum surface area of 425 hectares, maximum depth of 40 m, and drainage area of 860 km^2.

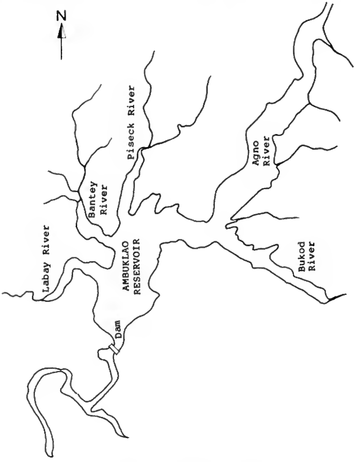


Figure 7. Ambuklao Reservoir.

3.1.2 Hydrobiological and fisheries aspects:

A recent hydrobiological survey conducted at the Ambuklao and Binga dams by Aypa *et al.*, (1983) showed physico-chemical parameters to be within acceptable limits for aquatic production (Table 11). Of the two reservoirs, Binga has slightly higher values of pH and dissolved oxygen. Recent values are lower than those obtained from surveys conducted at the early stages of the reservoirs. The two reservoirs have an abundant phytoplankton composed of diatoms, dinoflagellates, blue-green and green algae, and zooplankton consisting of rotifers, copepods, and cladocerans (Table 12). In Ambuklao, zooplankton formed 30 to 40% by volume (ml/m^3) of the total plankton, while in Binga it formed 20 to 30% of the total (Aypa *et al.*, 1983).

Very little is known about the fisheries of the Ambuklao and Binga reservoirs. Gracia (undated) noted the presence of gobies (*Glossogobius giurus*) and eels (*Anguilla* sp.) in both reservoirs, and the Japanese fish "doyo" (*Misgurnus anguillicaudatus*) in Ambuklao at the initial stages of operation.

Table 11

Average values of physico-chemical and biological parameters for Ambuklao and Binga reservoirs

Parameter	Ambuklao (1983)*	 (1955)**	Binga (1983)*	 (1960)**
Transparency, m	2.3	3	2.25	3.2
pH	6.4	6.7	7.2	7.8
Water temperature, °C				
Surface	23	28	23.4	25.8
5 m	22.2		23.1	
10 m	22		22.8	
15 m	21.5		22	
Dissolved oxygen, ppm				
Surface	6.2	8.6	6.4	8.54
5 m	5.5		5.3	
10 m	4.8		4.4	
15 m	4.7		3.7	
Total hardness, mg/l	1.9		2.1	
Plankton volume, ml/l	0.99		0.82	

* From Aypa *et al.*, 1983
** From Gracia, undated

Table 12

Plankton composition in the Ambuklao and Binga reservoirs (from Aypa et al., 1983)

Group/Species	Ambuklao	Binga
PHYTOPLANKTON		
Bacillariophyta	Nitzschia Melosira Tabellaria Surirella	Nitzschia Melosira Navicula
Dinoflagellata	Peridinium Ceratium	Peridinium
Cyanophyta	Anabaena	Anabaena Chlorococcus Oscillatoria
Chlorophyta	Pediastrum	Staurastrum Schroederia Pediastrum Volvox
ZOOPLANKTON		
Rotifera	Brachionus Filinia	Brachionus
Copepoda		
Cladocera	Bosmina Daphnia	Bosmina

After the initial introduction of fish (Table 13), the BFAR continued stocking fingerlings of tilapia, milkfish, mudfish, and other freshwater species in both reservoirs but detailed records of these introductions are lacking. Detailed fish catch statistics are missing, but the presence of large tilapia and carp in the catches of the 500 or so fishermen in the vicinity of the reservoirs show that these two species have established themselves successfully (Aypa et al., 1983). Also, casual observations by some people and reports of part-time fishermen in the area indicate that the fisheries in the reservoirs have stabilized and are providing about 50% of the protein requirement of the fishing families in the area (Aypa et al., 1983).

On the recommendations of BFAR, the National Power Corporation (NPC), which oversees the operation of the Ambuklao and Binga projects, shall implement shortly the establishment of a pilot fish cage culture project at selected sites within the two reservoirs (Castro, pers. comm.).

Table 13

Species and quantity of fish stocked in the Ambuklao and Binga reservoirs (from Gracia, undated)

Species	Numbers stocked	
	Ambuklao (1956)	Binga (1960)
Micropterus salmoides (black bass)	504	2,500
Lepomis macrochirus (blue gills)	40	250
Oreochromis mossambicus	6,000	2,000
Therapon sp.	1,000	200
Chanos chanos	5,000	2,000
Channa striata	6,000	1,000
Freshwater shrimps	1,000	-

3.1.3 Sedimentation problems:

The physical conditions in the watershed of the two reservoirs, coupled with the human activities of mining, agriculture and settlement, have resulted in high sedimentation rates which in turn have led to reduced storage capacities and shorter life spans of both reservoirs, thus minimizing the planned benefits from the development of the river system.

For example, the large inputs of silt have drastically lessened the volume of water available for fish production. Although at present the water is reported to have little suspended matter (Aypa et al., 1983), therefore allowing the possibility of cage culture, this may not be the case for long, if steps are not taken to correct the existing situation.

The problem of sedimentation has been the subject of several studies. Before the Ambuklao reservoir was completed, the Harza Engineering Company of the United States, the consultant for the feasibility study phase of the project, conducted sedimentation studies of the Agno River from 1954 to 1956. In 1954, prior to damming the Agno, another sedimentation study was done. In 1967, eleven years after the damming, the National Power Corporation conducted surveys to determine the extent of sedimentation in the Ambuklao reservoir. Results of these studies are compared in Table 14. Since 1967, the rates of erosion and sedimentation have increased considerably, mainly on account of the continued deforestation in the watershed. Some estimates suggest that the Ambuklao reservoir will function for only five more years (Aypa et al., 1983).

At Binga reservoir, the original 1961 capacity of about 92 $10^6 m^3$ at elev. 575 m, is said to have decreased to some 80.5 $10^6 m^3$ corresponding to a yearly sedimentation rate of about 1.9 $10^6 m^3$/yr inclusive of bed-load transport (ELC et al., 1979), lower than Ambuklao's average 2.4 $10^6 m^3$/yr. Total soil losses in the Agno watershed are estimated at 8.9 $10^6 m^3$/yr (ELC et al., 1979).

Table 14

Comparative volumes of sediment and bedload deposited in the Ambuklao Reservoir as shown by different sedimentation studies (from NPC, 1972)

	Harza	Thomas	NPC
Sediment volume (m^3/yr)	$2,500 \times 10^3$	$2,528 \times 10^3$	-
Bedload volume (m^3/yr)	134×10^3	196×10^3	-
Suspended and bedload volumes (m^3/yr)	$2,634 \times 10^3$	$2,724 \times 10^3$	$2,455 \times 10^3$*
Life span of reservoir (yr)	124	120	133

* Total reduction in reservoir volume after 11 years of operation is 27 $10^6 m^3$ or a deposition of $2,455 \times 10^3$, equivalent to 2.4 $10^6 m^3$ sediments per year.

The possibility of undertaking corrective and rehabilitative measures like desiltation of the reservoirs has been considered, but seems to be more costly than building a new hydroproject (Castro, pers.comm.). Instead, the San Roque Multipurpose Project in the lower Agno, originally scheduled for implementation in 1982 and later moved to 1986, is now being started as an alternative project under instructions of the President of the Philippines (Anon, 1982).

3.2 The Agno River Irrigation System (ARIS)

3.2.1 Current situation:

The Agno River Irrigation System is one of the biggest national irrigation systems being operated and maintained by the National Irrigation Administration (NIA). Formally inaugurated on 17 May 1957, it serves most of the larger-scale irrigated areas in the Province, mostly in the lowlands of eastern and central Pangasinan, covering approximately 41,569 hectares out of about 95,000 hectares of irrigated land in the Province (NWRC, 1983).

As in the Ambuklao and Binga projects, however, the ARIS is plagued by heavy sedimentation problems which started barely two years after its construction. These problems have grown into serious proportions over the years as a result of the excessive soil erosion in the watershed and the discharge of large volumes of mine tailings from big mines situated in the upper Agno district.

Out of an estimated volume of 8.9 $10^6 m^3$ of soil lost through erosion of the watershed annually, about 2.5 $10^6 m^3$ of sediment goes through the ARIS diversion weir located at the head of the extensive delta system between the San Roque dam site and the confluence of the Ambayabang River. In addition to these erosion-derived sediments, mine tailings together with decant water from, and diversions around, tailings dams operated by three companies, all flow into the ARIS. As a result, not only have the irrigation canals silted up; their water has also been contaminated with toxic metals deleterious to agricultural crops and aquatic life in areas affected by discharges of the irrigation canals.

In 1978, the Agno River was reported to have received an average of 26,380 mt of mine tailings daily from the Benguet Consolidated Inc. (which produces 50% of the country's gold output), the Philex Mining Corporation, and the Itogon-Suyoc Mining Company, all in the Benguet district (Tamayo-Zafaralla, 1983). It is not exactly known, however, how much of this volume enters the ARIS intake and is distributed by the main and lateral canals into the irrigated areas. It is also not known adequately what quantity of accumulated sediments are due to past mining activities and to incidental tailings dam failures, particularly between the Binga Dam and the ARIS diversion weir and intake structure (NACIAD *et al.*, 1981).

It is the opinion of the Bureau of Mines, however, that with the stricter controls imposed on mine tailings disposal by them in co-ordination with the National Pollution Control Commission, the actual volume of mine tailings and washings that flow into the Agno River is now less than it was over a decade ago (Obra, pers.comm.). Moreover, it has to be acknowledged that the erosion-derived sediments resulting from denudation and poor land use in the highly mineralized upper Agno may also contain heavy metals in solution and/or adsorbed to soil particles, particularly clays (NACIAD *et al.*, 1981).

Whatever the major sediment source is, the fact remains that the ARIS has been severely affected by siltation. Heavy sedimentation of the intake structure and the entire canal system has reduced discharge capacity to only 7.5 m/sec from the original design capacity of 28 m/sec (UNESCO/UNEP, 1979). Current estimates of the areas adversely affected by sedimentation in the Agno River catchment are 27,000 hectares of land, of which 18,500 hectares are NIA-administered areas and 8,120 hectares are served by the communal irrigation systems in the lower Agno (NACIAD *et al.*, 1981).

Crop yields have been significantly reduced by about 20 to 50% and crop losses estimated to cost approximately P14.8 million/yr due to a number of factors (UNESCO/UNEP, 1979). First, the accumulation of silt discharged together with irrigation water (Table 15), causes a cementing action on the soil and stunts growth of crops by inhibiting root absorption. Secondly, the high proportion of mine tailings reduces the fertility of the soil, as indicated by low organic matter content and reduced available P_2O_5. Thirdly, the highly-polluted irrigation water impedes with nutrient availability and uptake by the crops.

Similarly, the NIA has been incurring losses in the past several years as a result of the following:

1. non-payment of partial payment of farmers' irrigation fees, equivalent to about P12 million between 1960 and 1977;

2. payment of the farmers' claims for damages wrought by extensive siltation of their rice paddies; and

3. periodic desiltation/rehabilitation of ARIS canals and laterals, costing over P5 million since 1967 (NACIAD *et al.*, 1981).

The growing magnitude of the ARIS siltation problem and the resultant losses in revenue for both the farmers and the government, have prompted various agencies to take a closer look at the situation and initiate projects meant to alleviate the problem. Both long-term and interim mitigating measures have been proposed and are now lined up for implementation.

Table 15

Average volume of sediments (m^3/day) entering into and discharged by the ARIS, 1977 (from UNESCO/UNEP, 1979)

Month	Volume of sediments entering the ARIS	Volume of sediments discharged by ARIS
April	325	1.9
May	264	2.8
June	305	2.2
July	383	17.0
August	5,317	27.3

The NACIAD et al., (1981) have proposed that the following immediate and long-range measures be adopted:

1. Immediate:

   Clear Water Development Program;

2. Long-term:

   a) Construction of the San Roque Multi-purpose Project whose main feature is the establishment of a reservoir that shall act as a trap for mine tailings discharged in the upper Agno;

   b) ensuring an adequate design, construction, and operation of tailings dams throughout the economic life of all existing and future mining companies in the upper Agno basin;

   c) implementation of an extensive reforestation program with priority on the residual catchment above San Roque dam site and downstream of Binga Dam;

   d) rehabilitation of the ARIS infrastructure including construction of a redesigned intake system, and canal desiltation and improvement; and

   e) requiring all mining companies to implement comprehensive tailings dam bank stabilization measures.

3.2.2 Clear Water Development Project:

As the periodic desiltation of irrigated canals and the installation of settling basins at the farm level have been observed to be losing strategies and in view of the fact that the proposed San Roque Multipurpose Project shall take from six to seven years to complete, the NIA, in cooperation with the NACIAD, has embarked on the Clear Water Development Project for the ARIS. The project is aimed at developing small-scale diversion schemes to provide sediment-free supplementary irrigation water to about 11,000 hectares of agricultural land in the wet season.

In essence, the project involves diverting the clear water of small creeks and tributaries of the Agno River through canals and into the farmlands. Work on the diversion dams of three clear water sources has been completed. The completed project, though of a much smaller magnitude than the San Roque Project, is expected to provide immediate relief to many farmers in the Agno River Basin area (Nietes, pers.comm.).

3.3 San Roque Multipurpose Project

3.3.1 Features and purposes:

The project, to be located in the lower Agno River, some 30 km from Baguio City, shall have drainage area of 1,250 km^2, reservoir capacity of 990 $10^6 m^3$, active storage of 670 $10^6 m^3$, dead storage of 320 $10^6 m^3$, maximum surface area of 14 km^2, and maximum normal water level of 290 m a.s.l. (Table 16, Fig. 8).

The San Roque reservoir would regulate inflow for both power generation and irrigation use. Releases for power generation would be made through a tunnel extending from the reservoir to a power plant located immediately upstream from the existing ARIS diversion dam. An afterbay reservoir would be constructed adjacent to the diversion dam to re-regulate discharges from the power plant.

Projected to be the biggest multipurpose dam in Southeast Asia (Anon, 1982), the dam shall be built primarily for irrigation, power generation, flood control, and water quality improvement (ELC et al., 1979). It will render possible the year-round irrigation of 70,500 hectares in the Pangasinan plain with a partially diversified crop in the dry season. It shall also generate 780 GWh of primary energy plus up to 434 GWh of secondary energy to be made available at a distance of 150 km from Metro Manila. In addition, the project is expected to attenuate the flood problem in the Pangasinan plain and improve the quality of water in the lower Agno River by trapping all mine tailings produced in the watershed, the volume of which is expected to exceed 150 $10^6 m^3$ in the next 30 years.

3.3.2 Project rationale and justification:

The San Roque Multipurpose Project has been considered by the NACIAD et al. (1981), to be the most economical and the best technical alternative to reestablishing the viability of the Agno River Irrigation System which, at present, is suffering from heavy sedimentation problems and resultant economic losses.

The strongest justification for the San Roque Project arises from its projected capacity to entrap mine tailings and erosion-derived sediments from the upper Agno, and thus release clarified water to serve the irrigation and other requirements of the Province.

Table 16

San Roque multi-purpose project
(from ELC *et al.*, 1979)

LOCATION	Lower Agno River, Pangasinan, North Luzon
PURPOSES	Irrigation, power, flood control, water quality
HYDROLOGY	
Drainage area	1,250 m^3
Averge flow	94.2 m^3/s
Design flood	12,800 m^3/s
RESERVOIR	
Capacity	990 10^6 m^3
Active Storage	670 10^6 m^3
Dead Storage	320 10^6 m^3
Flood Cushion (el. 290-300)	150 10^6 m^3
Surfce Area at Max.N.W.L.	14 km^2
Max. Normal Water Level	290 m a.s.l.
Max. Exceptional Water Level	300 m a.s.l.
Min. Normal Water Level	225 m a.s.l.
DAM	
Type	gravel fill - central clay core
Max. height	210 m
Crest Length	1,130 m
SPILLWAY	
Capacity	15,600 m^3/s
Crest el.	280 m.a.s.l.
POWERHOUSE	
Type	shaft
Units	2-3 Francis vertical axis
Max. Gross Head	190 m
Min. Net Head	120 m
Installed Capacity	260-390 MW
Peaking Capacity (at max. head)	450 MW
Max. Discharge (3 units)	306 m^3/s
Primary Generation	780 GWh/year
Secondary Generation	377-434 GWh/year
IRRIGATION SYSTEMS	
Min. Net Irrigable Area (2 rice crops)	52,000 ha
Max. Net Irrigable Area (diversified crops)	87,000 ha

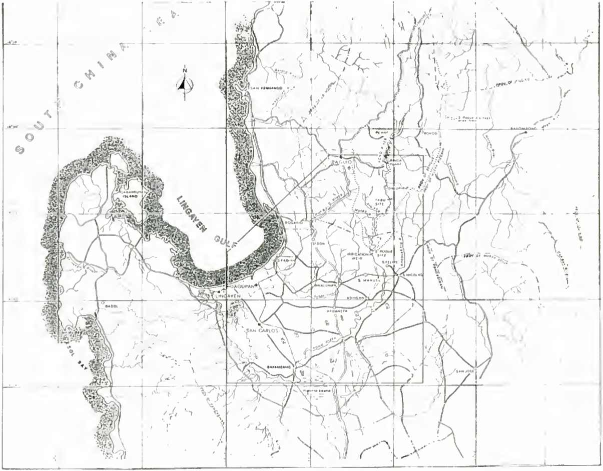


Figure 8. Map showing drainage area of San Roque project (from ELC et al., 1979)

The lower Agno River receives a heavy load of mine tailings and washings from three big mines located in the upper Agno district. These gold mines - Philex Mining Corporation, Benguet Consolidated Inc., and Itogon-Suyoc Mining - all exploit ores to obtain gold bullion and copper concentrates by cyanidation and flotation. Each of these mines also has tailings dams within their vicinities. At present, Itogon-Suyoc Mining, which is predicted to have an entire lifespan of 10 years, uses more than 600 kg/day of cyanide and produces a mine tailings output of up to 600 m t/day, which are disposed in tailings ponds formed along the banks of the nearby creeks. Benguet Consolidated, with an expected lifespan of 10 more years, uses over 300 kg of cyanide per day plus large amounts of flotation agents and mixes. It has a daily output of 300 mt of mine tailings which are impounded in tailings ponds formed with the help of rockfill dikes in the vicinity of the mill. Philex Mining, the largest mine in the Agno watershed with a projected lifespan of 40 more years, uses 400 kg of flotation agents daily to produce 25,000 m t of ore per day and tailings which comprise 90% of the overall tailings volume produced in the Agno watershed. Its tailings are impounded in a series of large tailings dams which are being gradually built up on a right bank tributary of the Agno, that meets the main stream in the stretch to be occupied by the future reservoir of the San Roque plant.

The tailings produced by the processing plants are conveyed by gravity launders to the tailings ponds formed by damming nearby creeks. To prevent the overtopping of these tailings dams, the natural waterflow from the river or creek upstream of the ponds is diverted by diversion works and tunnels. These structures notwithstanding, several cases of tailings dam collapse due to overtopping have been reported, resulting in the release of mine tailings in large amounts into the Agno River downstream of Binga reservoir. (The water released by the Binga Dam is practically pollution-free).

The sedimentation problem of the lower Agno River has prompted government agencies to look for possible measures to remedy the situation.

In 1975, a study was conducted by ELC (as cited in ELC et al., 1979) to compare two alternatives: 1) construction of tailings ponds near each of the mines; and 2) establishment of a 45-km conveyance along the Bued River (another long river in Pangasinan) and ending shortly before reaching the coastline, with the tailings to be accumulated in a sacrifice area.

In 1978, a study was carried out by the Japan International Cooperation Agency (JICA) (as cited in ELC et al., 1979). The study recommended the establishment of a tunnel-launder-pipe (TLP) system to convey the tailings to a sacrifice area in the Gulf of Lingayen. At one point in the past, the Bureau of Mine even proposed that all mine tailings be dumped into the Bued River which would then discharge them into the sea (Obra, pers.comm.).

The construction of tailings ponds near each of the mines is seen as an unattractive solution to the problem, considering that these would represent a no-return investment for the mining companies. The stability of the tailings ponds is therefore deemed very uncertain since the mining companies would settle for minimum expenses just to comply with the requirements.

The establishment of conveyance channels ending up near the Lingayen Gulf does not also represent an attractive alternative because of the possible impacts on the sacrifice area which would have a dump capacity of 150 $10^6 m^3$ (ELC et al., 1979). Neither does the proposal of dumping the tailings into the Bued River, which is a long way from the sea.

In view of the projected primary role of the San Roque Multipurpose Project in sediment entrapment and water quality improvement for irrigation, in addition to hydropower generation and flood control, its establishment has been considered the best option for the Philippine Government, especially since preliminary assessments of its environmental impacts showed that the project would indeed to ameliorate the existing problems.

The Feasibility Study on the project, which was prepared by ELC et al. (1979), claimed that since the reservoir shall trap the suspended sediments, the resulting silt-free water shall regain its scouring capability and tend to erode away the present obstructing sediments previously deposited in the Pangasinan plain, thus clearing out new channels and reinstating a good flow across the plains.

4. AGNO RIVER BASIN DEVELOPMENT AND FISHERIES

The 270 km long Agno River has never been considered a fishery resource. For apart from its indirect use as a source of water for fish ponds, there is no substantial capture fishery to speak of. Only limited data are available on the fisheries of the river itself, its tributaries, and the other water bodies with which it is interlinked. There is a lack of specific data on the effects of erosion, sedimentation, flooding, and pollutant discharges on water quality, freshwater and marine habitats, and fisheries. Although the BFAR annual statistics show the kinds and volumes of fish caught off the Lingayen Gulf, they do not say how much of it was caught in the areas directly influenced by the Agno River discharge. It is also not possible to assess the extent of decrease in fish yield in the estuarine and coastal waters as a result of pollution and silt load from the Agno.

The following discussion is therefore based on qualitative descriptions.

4.1 The environment of the Agno River: A recapitulation

The most damaging environmental factors relating to Agno River water resource development, including the fisheries component, are excessive soil erosion and soil contamination with heavy metals contained in sediments originating from the watershed. Continued deforestation, shifting cultivation, overgrazing, and forest burning, have all resulted in accelerated soil erosion leading to high sediment build-up in the Binga and Ambuklao dams, which have so far served as efficient traps.

Downstream of Binga reservoir, the clarified Agno River water receives further heavy input of erosion-derived sediments from the deforested watershed and from mines. The river water, recharged with a high sediment load, is diverted by the ARIS irrigation weir into its main intake structure, and into the ARIS canals and laterals, to irrigate some 40,000 hectares of agricultural lands of the Pangasinan plain.

Amongst the major tributaries of the Agno River is the Tarlac River. In lowlands, during flooding and high tides, the Agno connects with the Dagupan-Malabago-Sinocalan river systems which drain the urban areas of Dagupan, Santa Barbara, and Calasiao. The catchments of these rivers are intensively developed for irrigated rice farming, and have poor and largely inadequate waste disposal facilities even in the urban and industrial centres.

The Agno water discharging into the Lingayen Gulf thus carries a pollutant load consisting mostly of toxic metals and sediments from the upper catchment, fertilizer and pesticide residues from agricultural lands (which have been increasing their application rates in an effort to increase crop production), and domestic and industrial wastes from the urban centres.

4.2 Impacts of development on the fisheries

4.2.1 The Agno River:

Development projects in the Agno River have impacted the fishery resources of the basin largely on account of their interference with the quality of the fish habitat and the disruption of fundamental chains in the food web. The impact of the hydroprojects on fisheries by way of habitat transformation (from lotic to lentic) and loss of seasonal inundation appears to be less than impacts of toxic metals, pesticide and fertilizer residues, domestic wastes, and suspended sediments. Changes in feeding, growth, reproductive, and mortality rates of fish are believed to be consequences of the deterioration of the quality of the habitat (UNESCO/UNEP, 1979; NACIAD et al., 1981). Such a situation is apparent in the individual fishery zones along the stretch of the river from its source to its outlet into the sea.

4.2.2 The reservoirs:

The shortage of pre- and post-impoundment data for the Ambuklao and Binga reservoirs makes an accurate evaluation of the impact of their construction on the Agno River fisheries rather difficult. Hydrobiological surveys conducted by the BFAR in 1955 and 1960 when the two reservoirs just filled showed the essential physico-chemical parameters to be within optimum levels for aquatic biological production and noted the presence of gobies and eels. Since then, the BFAR has stocked the reservoirs with fingerlings of tilapias, Therapon sp., milkfish (Chanos chanos), mudfish (Channa striata), blackbass (Micropterus salmoides), blue gill (Lepomis macrochirus), and the giant freshwater prawn (Macrobrachium sp.). No follow-up studies have been conducted subsequent to these introductions which makes evaluation of the success of the stocking programme impossible. The only base for making tentative conclusions on the status of the fisheries of the two reservoirs are the verbal reports of catches of fish by the fishermen in the area. No official fish yield figures are available. As a result of the input of large quantities of nutrient-rich sediments from the watershed, there is an abundance of phytoplankton and zooplankton (Aypa et al., 1983). The reservoirs would therefore appear to have a good fisheries potential.

To supplement natural fish production in the reservoirs, the culture of tilapia in floating cages shall be pilot-tested by the National Power Corporation in cooperation with BFAR. The probability of success of this scheme seems to be high on account of the high primary productivity of the reservoirs, which is essential to fish growth and survival. A land-based tilapia hatchery-nursery complex is also being proposed together with the installation of the fish cages. This will ensure the availability of fish seed for cage culture and for direct stocking in the reservoirs. The BFAR has also proposed to undertake an evaluation of the present fish stocks in the reservoirs, to be used as a basis for appropriate stocking and re-stocking of suitable fish species (Aypa et al., 1983).

4.2.3 Fisheries downstream of Binga Dam:

In mid-1979, hydrobiological surveys were conducted by BFAR personnel along 110 km from the upper portions of the Agno River to its lower reaches near its mouth in the Lingayen Gulf. This survey, conducted by Gracia et al. (1979), concluded that the upper Agno is poor in fish and hardly ever fished except in the rainy season when water level is high. Instead, the people carry out gold-panning.

The scarcity of fish in the upper Agno may be due primarily to the poor water quality as characterized by low dissolved oxygen transparency and pH values with lower values found higher upstream (Table 17). This may be due to the heavier silt load of water closer to their point of origin, in this case, the water discharged by the irrigation systems located nearer the ARIS main intake structure (UNESCO/UNEP, 1979). Natividad and Magsumbol (1979) found that except for the pH of river water in the municipality of Bayambang, the measured physico-chemical parameters improve as the river progresses downstream (Table 18). The lower Agno has a better fishery than the upper reaches. Experimental fishing by the BFAR in the lower Agno revealed the presence of mullet, carp, tilapia, mudfish, and freshwater snails (locally known as "bisokol") (Natividad and Magsumbol, 1979). The numbers of freshwater fish species, however, are perceived to be lower than in the past (NACIAD et al., 1981). Also, it has been observed that some aquatic plants such as *Vallisneria* spp., and benthic organisms like whelks, mud crabs, and tubiferous worms have become very scarce in the river system (NACIAD et al., 1981). These changes may result from the increased sedimentation and pollution. The present Agno River system is obviously no more capable of supporting a rich biomass and diversity of aquatic life.

Table 17

Average values of selected physico-chemical parameters recorded along the Agno River, 10-19 July 1979 (from Gracia et al., 1979)

Municipality	Water temp. (°C)	Transparency (m)	D.O. (ppm)	pH
Urdaneta	25.0	1.58	6.29	6.17
Sta. Maria-Asingan	25.2	1.33	5.94	5.75
Asingan-Tayug	26.5	0.35	4.5	4.0
San Manuel-Tayug-San Nicolas	24.5	0.72	4.16	3.5
San Nicolas	25.6	0.82	3.98	3.25

Note:

Average of measurements taken at six sampling stations per municipality.

The municipalities are arranged in the order of increasing proximity to the river's origin, with San Nicolas being the closest to the source.

The impacts of silt, heavy metals, and pesticides on aquatic organisms are well known. The UNESCO/UNEP Report (1979) summarized the effects of siltation on aquatic organisms as follows: "Siltation destroys spawning grounds and eggs of fish, and kills insects that are essential as fish food. It restricts light penetration and reduces growth and photosynthetic activity of oxygen-producing aquatic plants. Silt suffocates fish and irritates gill membranes, thereby contributing to fish stress and increasing their susceptibility to disease." Furthermore, the gradually increasing concentration of silt leads to a change in dominant species, with fish feeding visually unable to stay while those using fish sensors for locating food may move in (Petr, 1983). The effects of suspended and sedimentary loads are manifested by increased competitiveness of various species, occurrence of diseases, gradual decline of, or change in, the composition of the population or the whole ecosystem, and the reduction of fish stocks by mass mortalities (UNESCO/UNEP, 1979). To complicate the situation further, toxic metals in the mine tailings discharged into the upper Agno eventually settle into the river, delta, and estuary where they become available to benthic algae and infauna which may accumulate them to concentrations several times over those which occur in the ambient environment (Everett and Associates, 1980).

Table 18

Average values of selected physico-chemical parameters recorded along the Agno River, 30 March - 9 April 1979 (from Natividad and Magsumbol, 1979)

Municipality	Water temp. (°C)	Transparency (m)	D.O. (ppm)	pH
Bugallon	24.4	2.8	6.54	6.4
Aguilar	23.4	2.7	6.3	8.0
Urbiztondo	23.9	2.9	7.0	8.3
Bayambang	25.4	0.75	7.1	5.9
Alcala	24.6	0.75	6.86	8.7
Villasis	24.8	0.75	6.92	8.5

Note:

Average of measurements taken at five sampling stations per municipality.

The municipalities are arranged in order of increasing proximity to the river origin, with Villasis located farthest upstream.

The Fe^{++} in water from mine drainage may precipitate out as $Fe(OH)_3$ and be carried as a flocculant in colloidal suspension which has a detrimental effect to fish, as it impairs gill respiration (Everett and Associates, 1980). Mercury at concentrations above 0.30 mg/l $HgCl_2$ has been shown to cause a significant inhibition of enzyme activity, act as a vascular poison, cause damage to accessory respiratory organs, decrease oxygen consumption, and cause blindness in *Oreochromis mossambicus* (Spehar *et al.*, 1981). Cadmium has been reported to inhibit growth of fish while lead has been known to cause ovulation stress, loss of muscular coordination, balance, deformity, and embryo and fry mortality in cichlids (Spehar et al., 1981).

In the Agno River system, the problem of high levels of heavy metals may be further complicated by the presence of pesticide residues or associated polyphosphates present in agro-chemicals, on which the heavy metals may adsorb (NACIAD et al., 1981), and cause pathological conditions in fish, such as disease and/or deformity (Spehar et al., 1981). This situation may actually be more serious than it appears, especially if it is considered that farmers have been applying significantly more fertilizers and pesticides in an effort to increase their yields, which have been severely reduced as a result of the ARIS sedimentation problem (UNESCO/UNEP, 1979).

Pesticide use is also known to have a negative impact on the paddy, canal, pond, and mainstream fish. Tissue samples of fish taken from Pangasinan were found to contain excessive loads of gamma betaheptachlor (4.35 - 27.36 µg/kg of fish) and dieldrin (0.83 - 32.08 µg/kg of fish) (NACIAD et al., 1981), compounds known to have a particularly toxic effect on fish. At the FAO/WHO recommended acceptable daily intake (ADI) of 10 µg/kg of body weight for gamma betaheptachlor and 0.1 µg/kg body weight for dieldrin, it is the low income families who would be the most affected since fish constitutes their main protein source.

4.2.4 Brackish-estuarine fisheries:

Estuaries, coastal swamps and mangroves are ecologically important areas which serve as spawning, nursery, and feeding grounds for a variety of commercially valuable fish and shellfish. In the Agno River the major areas of impact from the point of view of water resource development are the coastal fringes along Lingayen Gulf near the mouth of the Agno River, and the Dagupan estuary area and the brackishwater fishponds in the coastal municipalities of Pangasinan. The occurrence of heavy metals, is at least partially attributable to contaminants flowing through the river system. Concentrations of Hg, Cd, and Pb above acceptable limits in waters of Lingayen Gulf (Table 5) present threat not only to the lower aquatic organisms but also to man, the ultimate consumer. These heavy metals can be bound by organic detritus and subsequently concentrated in the tissues of detritus-feeders (e.g. oysters, shrimp larvae, mullets) and by plants (e.g. nipa palms) (NACIAD et al., 1981). The input of pesticides and fertilizers via agricultural practices has created unrecognized problems for aquaculture and for the river/marine/coastal wild fish stock.

Mining activities which result in the input of large volumes of mine tailings into the Agno River system also destroy the mangrove ecosystem by siltation and a high turbidity of water, which also negatively affects benthic communities and threatens adjacent coral reefs. Siltation on coral reefs is known to be a major source of their destruction (Soegiarto, 1980).

Compounding these problems of heavy metals and pesticides are the waste disposal problems posed by human activities. In mangroves, which act as a pollutant sink, microbial action under appropriate conditions may deposit heavy metals as insoluble sulfides (NACIAD et al., 1981). Enterobacteria which are known to readily absorb heavy metals, abound in the sewage-polluted waters and local streams of the Dagupan-Calasiao estuary area which is connected with the Agno River during floods. For example, zinc and cadmium are known to reach concentrations in sediments as high as 100,000 ppm and 30,000 ppm, respectively (NACIAD et al., 1981). The probable implication of this on estuarine fish and shellfish production, especially in the Dagupan estuary where oyster culture is being promoted, is evident.

A similar situation may exist in brackishwater fishponds in the lower Agno, which have been shown to contain high dissolved concentrations of heavy metals (0.15 ug/l lead and 0.1 - 0.27 ug/l Hg) as a result of the use of the contaminated water from the Agno River (GOPA, 1983). It is then highly possible that fish ponds in the Dagupan-Binmaley-Lingayen area would be subject to long-term heavy metal contamination through biological release and recycling associated with flooding, flushing, and use of the Agno River as a supply source (NACIAD et al., 1981). Furthermore, the possibility also exists for the accumulation of toxic metals by algae grown in these ponds and their subsequent transfer up the food chain.

To conclude, the brackish-estuarine zone of the Agno River Basin is a highly stressed ecosystem, mainly as a result of ecological imbalance due to various development activities in the upper catchment area. The long-term accumulation of mineralized sediments and heavy metals, the chronic application of agrochemicals, and the indiscriminate disposal of domestic and industrial wastes into the Agno River system, have altered the natural habitats for aquatic organisms by their interference with water chemistry and sediment quality and quantity.

4.3 Multi-purpose river basin development and fisheries

The concept of multipurpose development is and shall be always a challenge to planners. For while multiple use may be viewed as a "group of industries, farmers, municipalities, and government agencies, all cooperatively using a single water supply without encroaching on the rights of others, this utopian situation does not now exist anywhere and is not likely to exist ... (as) it is virtually impossible to use water for one purpose without interfering with other beneficial uses" (Cairns, 1972). The fact remains that "of several useful services of a typical river system, some are competitive, some neutral, and a few complementary" (Crutchfield, 1972). And as is often the case, among several potential uses of a river, the fisheries sector falls low in the order of priorities for development. Power generation, irrigation, and flood control usually occupy first positions in the hierarchy of planning goals, which, until recently, has neglected the fisheries.

In the Philippines, as in the other developing countries of Asia and Africa, high population growth rates necessitate the proper development and management of drainage basins for domestic, agricultural, and industrial uses. Like in Africa, the fisheries are generally treated as incidental, though not altogether ignored, often receiving little or no attention in the planning and execution of land and water resources development (cf. Awachie, 1981; Litterick, 1981).

Over the past three decades, since the first hydroproject in the country was established in the upper Agno, river basin development has been geared towards the satisfaction of the more economically rewarding goals of hydroelectricity, irrigation, and flood control, without much consideration for the other sectors, especially the fisheries, which are likely to be affected by the development. Rather than think of the possibilities of fish stock depletion and the conservation of endangered fish species, government planners have confined their attention to hydroelectric power production and an irrigation scheme and to secondary benefits like prevention of flood losses. Thus, no pre-impoundment fisheries surveys were conducted before dam construction (Gracia and Magsumbol, 1983). The absence of such data, therefore, makes any evaluation of the impact of these projects on the original fish fauna and fisheries difficult. Lack of statistics on fish yield and fisheries in the reservoirs also hinders fisheries planning and management. The poor state of the Agno River fisheries and the environment is also an indication of administrative weakness and poor management. In 1981, the problems were summarized by NACIAD et al. (1981) as follows: Administrative responsibilities for (the) various components of natural resource management are segregated and interrelationships and cooperation at the provincial and regional levels among agencies appears to be minimal. Overall responsibilities for environmental policy and investigations and pollution problems lie with the National Environmental Protection Council (NEPC) and the National Pollution Control Commission (NPCC), agencies not yet represented at the regional and provincial office levels. The National Economic Development Authority (NEDA) regional office is the agency which has the capability and responsibility to plan for resource allocation and development but at this stage, environmental and pollution-related problems experienced by the local people can only be dealt with indirectly through representations with selected officials.

What further aggravates the situation is the fact that most of the effects now being felt by the numerous families and communities in the river basin are caused by environmental degradation and policy decisions outside Pangasinan - the origin of the sedimentation problem being poor watershed management and mining practices in Benguet Province. Consequently, the decisions on mitigating measures to alleviate or rectify major environmental problems are beyond the influence of provincial representatives. For example, projects on irrigation works rehabilitation and large-scale reafforestation of the watershed can only be approved and implemented by national agencies.

At the national level, decision-making tends to involve multiple agencies with poorly defined channels of control and weak linkages. Fisheries has been mostly considered only as an afterthought. This explains why fisheries, especially those initiated several years ago, were usually unplanned activities, without much prior thought and preparation. The fish stocking programme in man-made lakes is a case in point. With no benchmark ecological data, no previous biological studies, no stock data and catch statistics, a stocking programme was initiated. In the Ambuklao and Binga reservoirs, fingerling dispersal was a one-time affair. Both the poor policy directives and management on behalf of a number of agencies seemed to be behind this. After the initial effort at fish stocking, there was hardly any subsequent activity to determine its success or failure, thereby rendering futile any attempt to make a thorough evaluation of the merits of the fisheries management programme (Baluyut, 1983).

5. PROSPECTS FOR FUTURE DEVELOPMENT

Inspite of the slow start of the Agno River fisheries, the prospects for change and improvement look promising. Recently, there has been a growing interest and involvement of government agencies and, in particular, of the BFAR in the Agno River. The BFAR has sent out survey teams to the upper and lower Agno River to look into the possibilities of aquaculture in the existing reservoirs and to conduct pre-impoundment surveys as part of the planning activities for the San Roque Project. Aypa et al. (1983) are confident that the floating cage culture project they are establishing in the Ambuklao and Binga reservoirs would succeed on account of the high primary productivity of the water. Fisheries officials and senior level personnel have also become more actively involved in the river basin development planning and management. Unlike before when multipurpose water projects were established without having taken the interest of fisheries into consideration, the pre-impoundment survey conducted recently on the lower Agno River at the San Roque dam site of the existing fishery resources will serve as a basis for future fisheries programmes. The Asian Development Bank-assisted Aquaculture Development Project for implementation by BFAR in selected brackishwater fish ponds in Pangasinan promises to optimize resource utilization through intensification rather than opening up new mangrove areas for extensive fish pond development. Under this project, participating fish pond owners/operators shall be provided with credit assistance for pond renovation and redesign and purchase of inputs needed for intensified prawn and/or milkfish culture, in addition to the provision of various support facilities like hatcheries and ice plants, training and extension, and environmental management.

On a broader planning and administrative level, two large development projects aim to alleviate present problems and difficulties and give the people of Pangasinan something to look forward to. First, the San Roque Multipurpose Project, for immediate implementation by the National Power Corporation with funding assistance from the Japanese Government, promises to provide a much needed boost to the river basin economy by serving as a sediment trap, while at the same time generating power, irrigating farmlands, and controlling floods. The project is deemed of critical importance in reestablishing the viability of the Agno River Basin environment by preventing further accumulation of heavy metal-laden sediments and mineralized clay particles from the watershed. The silt-free water to be released by the dam is expected to exert a scouring action on the thick sediment deposits in the river and its tributaries, the ARIS irrigation canals, and the coastal zone, with the concommitant improvement of the environment and the renewal of the fisheries and aquatic resources.

As a corollary measure, the reafforestation and proper management of the Agno watershed, begun in 1981, shall be undertaken on a continuing basis. The Bureau of Forest Development has already replanted about 8,832 out of a total projected area of 23,250 ha. Jointly with FAO/UNDP, it has prepared the investment portfolio of the Multi-Use Forest Management Project aimed at the comprehensive rehabilitation of the Upper Agno district as a long-term ameliorative measure for the heavy siltation problem. This US $32.4 million project for eventual foreign funding has been prepared using the Integrated Area Development (IAD) approach, following existing political and administrative set-ups, and with the full cooperation and coordination of the local and national agencies. It aims at an accelerated agricultural and fisheries production; intensified forestry, agrarian reform, and cottage industry activities; credit provision and management; water supply and sanitation; nutrition improvement; vocational and technical skills training; infrastructure development; and environmental protection.

All these projects and programmes, which directly or indirectly seek the ultimate rehabilitation of the Agno River Basin, seem to have been predicated on the complementary and interrelated strategies of proper and rational land utilization on the one hand and water resources development and management on the other. Development projects like those proposed to be undertaken by the PIADP and economic activities likely to be stimulated by the establishment of the San Roque Multi-purpose Project and the Aquaculture Development Project, are projected to create new employment opportunities, increase incomes, and generate other spin-off effects, all leading towards greater cultural opportunity, socio-economic uplift and environmental harmony.

6. REFERENCES

Awachie, J.B.E., Some general considerations on river basins in Africa
1981 and their management and development in relation to fisheries. CIFA Tech.Pap./Doc.Tech.CPCA, (8):2-23

Aypa, S.M., A.M. Galicia, Jr. and R. Magsumbol, Hydrobiological investi-
1983 gation and survey on suitable sites for fish cage project in Ambuklao and Binga dams, Benguet Province. Quezon City, Bureau of Fisheries and Aquatic Resources. (mimeo)

Baluyut, E.A., Fish introductions in lakes and reservoirs in the ASEAN
1983 region: a review. FAO Fish.Tech.Pap., (236):82 p.

BFAR (Bureau of Fisheries and Aquatic Resources), Fisheries statistics of
1981 the Philippines. Fish.Stat.Philipp., (31)

Cairns, Jr. J., Rationalization of multiple use of rivers. In River
1972 ecology and man, edited by R.T. Oglesby, C.A. Carlson and J.A. McCann. New York, Academic Press, pp.421-30

Crutchfield, J., Multiple use of river systems: an economic framework.
1972 In River ecology and man, edited by R.T. Oglesby, C.A. Carlson and J.A. McCann. New York, Academic Press, pp.431-40

Dasmann, R.F., J.P. Milton and P.H. Freeman, Ecological principles for
1973 economic development. New York, John Wiley and Sons

ELC (Electroconsult S.p.A.)/EDCOP (Engineering Development Corporation of
1979 the Philippines), San Roque multipurpose project. Feasibility study. Main report. Metro Manila, EDCOP

Everett and Associates, Estimates of geochemical processes and chemical
1980 concentrations in the Fly River drainage that may result from development of the Ok Tedi Project, Western Province, Papua New Guinea. 2 vols. (mimeo)

GOPA Consultnts, Aquaculture development project technical assistance
1983 study. (Draft final report). Bad Homburg, West Germany, GOPA Consultants

Gracia, D.M., General information on Philippine reservoirs. Quezon
n.d. City, Bureau of Fisheries and Aquatic Resources. (mimeo)

Gracia, D.M. and J.M. Natividad, The Agno River: Its fishery resources,
1979 hydrobiological parameters, and potential land uses. Survey report. Quezon City, Bureau of Fisheries nd Aquatic Resources (mimeo)

Gracia, D.M. and R.M. Magsumbol, Report on the pre-impoundment survey of
1983 lower Agno River (San Roque Dam). Pangasinan, August 25-30, 1983. Quezon City, Bureau of Fisheries and Aquatic Resources, Fish Propagation Division. (Unpubl.Rep.)

Hanson, .J. and Koesoebiono, Settling coastal swamplands in Sumatra - a
1977 case study for integrated resource management. Environmental Research Training Project. Bogor, Indonesia, Center for Natural Resources Management and Environmental Studies, Bogor Agricultural University

Litterick, M., River basin management and development in Kenya. CIFA
1981 Tech.Pap./Doc.Tech.CPCA, (8):25-33

NACIAD et al., Pangasinan integrated area development project. Final
1981 report. Vols.1-4. Quezon City, National Council on Integrated Area Development

Natividad, J.M. and R.M. Magsumbol, Inventory survey and hydrobiological
1979 investigation on the upper Agno River. Quezon City, Bureau of Fisheries and Aquatic Resources (mimeo)

NEDA (National Economic Development Authority), Philippine statistical
1982 yearbook. Manila, NEDA

NPC (National Power Corporation), Management of Ambuklao - Binga water-
1972 shed and sedimentation of Ambuklao reservoir. Paper presented to the Tenth Regional Conference on Water Resources. UN/ECAFE, 18-25 Sept. 1972

NPCC (National Pollution Control Commission), Water quality criteria and
n.d. rules and regulations relating to water pollution control. Manila, NPCC

NWRC (National Water Resources Council), Philippine water resources.
1976 First national assessment report, No.(19). Quezon City, NWRC

__________, Agno River basins - Central Luzon. Framework plan. In
1983 Regional water resources development strategies. Vol.3. (Draft MS)

Petr, T., Conflicts arising for fish and fisheries from poor land use
1983 and urbanization. FAO Fish.Rep., (288):76-82

Philippines, National Environmental Protective Council and National
1983 Council on Integrated Area Development (NEPC and NACIAD), Ecological profile of Pangasinan. Report. Manila, NEPC/NACIAD

Soegiarto, A., Status report on research and monitoring of the impact of
1980 pollution on mangrove ecosystems and its productivity in Indonesia. Country paper presented at the SCSP-FAO/UNEP Expert Consultation Meeting on impact of pollution on mangrove ecosystems and its productivity in Southeast Asia. Manila, Philippines. 4-8 Feb. 1980 (mimeo)

Spehar, R.L. et al., Effects of pollution on freshwater fish. J.Water
1981 Pollut.Control Fed., 53(6):1028-76

Tamayo-Zafaralla, M., Conflicts between fisheries and mining, industrial-
1983 ization and pollution of inland waters in the Philippines. FAO Fish.Rep., (288):83-7

UN, Integrated river basin development. Report of a Panel of Experts.
1970 Revised edition. New York, United Nations

UNESCO/UNEP, Programme for the Development of Ecological Pilot Projects
1979 in Tropical Forest Areas, Integrated approaches to coastal zone management and river basin development through implementation of pilot projects at Puerto Galera and Agno River Basin, Philippines. Final report. December 1979. Vol.1 Paris, Unesco, MAB Secretariat, 247 p.

Anon, Marcos tells energy officials to hurry. Philipp.Daily Express,
1982 26 October 1982 issue

B. THE NAM PONG BASIN (THAILAND)

by

Thiraphan Bhukaswan
National Inland Fisheries Institute
Department of Fisheries
Bangkok
Thailand

ABSTRACT

The main features of the Nam Pong River Basin Development in Thailand are a hydroelectric dam, and a downstream situated irrigation system. Since the dam closed the river in 1965, fishing has considerably improved the diet and income of a number of farmers. In 1978, there were 5,628 fishermen operating on the Ubolratana reservoir, who captured 1,846 tonnes of fish which is equal to a fish yield of 47 kg/ha/yr. Fisheries management practices have included stocking of 19 species of fish, some of which have become prominent in fish yields: Trichogaster pectoralis dominated the yields between 1969 and 1972. Fish processing involves smoking, salting and fermenting. In 1982, aquaculture in the Nam Pong River Basin was practised in 4,336 fish ponds and other water bodies, with a total surface area of 665 ha, and in 437 ha of paddy fields; the total fish production was 1,134 tonnes. In "other water bodies" stocking has improved annual fish yield from 90 kg/ha to 300 kg/ha. Socio-economic evaluation of fisheries has shown differences in profit in different areas. In one village, 80% of the fish captured were consumed in households, with the rest sold or bartered. In another area, 80% of fish captured were sold, while the rest was consumed.

An irrigation system for 42,287 ha of land downstream from the reservoir is almost completed, and cultivation practices are shifting from one rice crop per year to continuous rice production.

A benefit-cost analysis has shown that the river basin development project benefits are negligible, in other words, the project has been a poor financial investment.

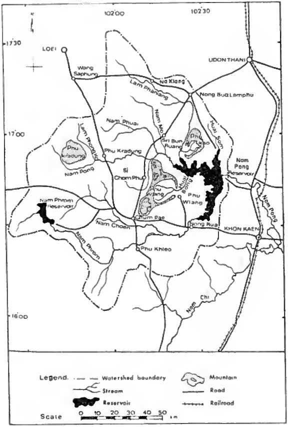


Figure 1. The Nam Pong River Basin

1. INTRODUCTION

The Nam Pong River Basin covers an area of about 12,560 km^2, partly in the provinces of Petchaboon, Loei, Chaiyaphum, Udon Thani and Khon Kaen. Geographically, it lies between 16° and 17°30'N and 101°15' and 102°45'E (Fig. 1). The upper part of the basin is mountainous and covered with different forest types. The lower part consists mainly of paddy fields, and is more heavily populated. Five major rivers, i.e. the Huai Som, Lam Phaniang, Nam Pong (including Nam Mo and Nam Phuai), Huai Bong and Nam Choen (including Nam Phrom), enter the reservoir.

The Nam Pong or Ubolratana Dam impounding the water runoff from the Nam Pong Basin for power generation was completed in 1965. The reservoir at its maximum storage elevation of 182 m above mean-sea level (MSL) has a surface area of 410 km^2 with an average depth of about 16 m, and the maximum storage of 2,550 million m^3. At its minimum water level of 176 m, its surface area is 160 m^2, and the average depth is about 12 m (Fig. 2). The water discharged from the power house, or spilled, enters the Nong Wai diversion which irrigated 500 km^2 of land. In 1983, about 90% of this area was already irrigated. The use of water for irrigation determines the quantity and quality of water received by water bodies situated downstream.

2. PROFILE OF THE NAM PONG RIVER SYSTEM

2.1 Topography

The land surface in the watershed is generally undulating and sloping towards the east and southeast. The elevation of the relatively flat area around the reservoir is about 190 m MSL. The western watershed, from which the Nam Pong and the Nam Phrom originate, consists of many mountain ranges with an average elevation of 900 m MSL, and up to 1,300 m MSL at Phu Kradung. To the east of the western boundary, between the Nam Pong and the Nam Phrom, the Lam Choen originates from Phu Tham Porn, the elevation of which is about 260 m MSL. The Nam Pong and Nam Choen flow eastwards directly into the reservoir, while the Nam Phrom merges with the Nam Choen before discharging into the reservoir. In the north are mountains with the elevation of about 540 m MSL. The Lam Phaniang originates from the western region of Phu Phan and flows southwards into the reservoir. The southern watershed boundary at Phu Khieo has an elevation of up to 1,000 m MSL (Fig. 1).

The Ubolratana Reservoir (Fig.2) is relatively shallow with a depth ranging from less than one meter to 20 m. The inundated land was mostly paddy fields interspersed with shrubs and trees. The downstream and the irrigating areas are level to gently undulating. The elevation there ranges from 153 to 200 m MSL.

2.2 Climate

The climate is tropical monsoonal, with clearly defined wet and dry seasons. The hot season is from February to April, when the weather is hot and dry with the temperatures from 20°C at night to over 35°C at mid-afternoon. During the rainy season, covering the period from May to October, the southwest monsoon brings rain from the Indian Ocean. Heavy rainfalls occur in August and September, with a very heavy rainfall caused by typhoons originating in the South China Sea. Because of the rainshadow caused by mountain chains between the central plains and the northeastern plateau, typhoons are the major source of precipitation in Nam Pong River Basin. The average rainfall in this area is approximately 1,200 mm and is heaviest along the high ridges. The temperature during this period is moderate, ranging from 23°C to 32°C. The rainy season is followed by the cold season (November to January), when the northeast monsoon from

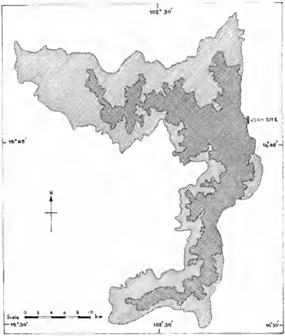


Figure 2. The Ubolratana Reservoir at maximum and minimum water levels

mainland China dominates the region. The weather is cold and dry, with temperatures ranging from 12°C at night to 30°C in mid-afternoon.

2.3 Soils

Soils of the Nam Pong Basin were developed from parent materials of Pleistocene age and most of the soils are distinctly pale. In general, soils of the high mountains and steep hills in the western part of the basin area are latosols and lithosols and on the rolling hills and high plains in the east, soils are sandy ferruginous latosols. The eastern part of the basin is dominated by low humic grey soils and grey podzolic soils or red-yellow podzolic soils on alluvium. The major parent materials are old alluvium sediment, residum, and slope colluvium of acid rocks and granite. The soils have a thin surface horizon and they normally have a weak horizon development. Surface soils are mostly sandy loam or loamy sand, with a sandy clay or a sandy clay loam in the subsoils. The dry surface layer is generally a light grey colour which changes to brown when moist. Subsoils are yellowish-brown or reddish-brown in colour. The soils have a pH ranging from 4.5 - 5.0 (Wacharakitti et al., 1979).

These authors also described the soil characteristics on steep land in the west and on some hilltops in the eastern part of the basin.

2.4 Hydrology

The water balance study in the Ubolratana reservoir indicates that the average annual rainfall over the catchment area of the reservoir is 1,200 mm, or 14,400 million m^3. The averge annual runoff collected by the reservoir is 2,340 million m^3, of which, around 14% is the result of direct precipitation into the reservoir. It is estimated that, of the annual inflow, approximately 15% is lost by evaporation, 60% is the regulated outflow, 20% is lost by seepage and the rest is being temporarily stored in the reservoir (Sethaputra et al., 1979). They have also reported that the groundwater levels, upstream and downstream of the reservoir, fluctuate in a seasonal cycle. On the averge, the water level drops to 5 m in the dry season. Groundwater discharges into the reservoir and the streams throughout the year. The reservoir appears to have only weak interaction with the surrounding aquifers.

Prior to the construction of the Ubolratana Dam on the Nam Pong River, flooding of large tracts in the lower part area used to be a regular hazard. This did not only impede, but made agriculture virtually impossible in the wet season. Completion of the Ubolratana Dam reduced the flood peaks in the Nam Pong River. As a result, flooding occurs less frequently. However, the dam is less effective in flood control aspects as one moves further downstream.

2.5 Water quality

The quality of water in upstream tributaries is subject to watershed characteristics including morphology, geology, soils, plant coverage and land use, climate, hydrology and human related activities. All tributaries in the watershed, except the Nam Choen, have very low dry-season flow. In places, the water in the streams is impounded by earth dykes for dry-season use. The Nam Choen is kept running throughout the dry period by the water released from the Nam Phrom reservoir (Chulabhorn Dam). The runoff on the small tributaries occurs intermittently, while that in larger tributaries is continuous. The peak flood of the year is between late September and mid-October. Suspended particles, chemical components including nutrients, reach the reservoir mostly during the wet season. Heavy rains always result in high erosion, and this increases the amount of suspended particles with their organic and inorganic components in water.

In all tributaries the dissolved concentration of the essential nutrients (N,P,K) is usually low. This is because soils in watersheds of these tributaries are highly eroded with a low fertility. Faecal pollution has been recorded in all the tributaries throughout the year. Concentrations of dissolved solids are normal.

2.6 Groundwater

Groundwater plays a minor role in furnishing village domestic water supplies in the Nam Pong River Basin. The use of groundwater for irrigation has not yet been reported. The interaction of the fluctuating reservoir water level with groundwater is quite complex, both hydrologically and hydraulically. It was observed that the groundwater in Khon Kaen increased significantly in 1966, just after the first reservoir filling, and showed a mild increasing trend throughout the following years (Sethaputra et al., 1979). They believed that the increase in ground water level was probably the result of the impoundment of water in the reservoir. This observation may indicate that the reservoir is probably losing water to the confined aquifers as seepage.

The upstream groundwater levels showed seasonal fluctuations. The level rises during the rainy season particularly in June and July and declines during the dry season. Fluctuations are also due to groundwater movement into or out of the aquifers and evapotranspiration losses. Upstream groundwater movement was found to follow a similar pattern of surface drainage. Groundwater discharges into the Nam Pong River and the Ubolratana reservoir. However, the reservoir appears to have weak interaction with the surrounding water-table aquifers.

Seasonal fluctuations of downstream groundwater levels are similar to those upstream. Evapotranspiration losses and discharge to the Nam Pong River are believed to account for the decline of groundwater level in the dry season. The decline of groundwater levels are correlated resonably well with the estimated evapotranspiration in the irrigation area (Sethaputra et al., 1979).

2.7 Fish and the fisheries in the Nam Pong River system

The Department of Fisheries conducted a fishery biological study in the Nam Pong River system prior to the impoundment of the Ubolratana reservoir (Sidthimunka et al., 1968). They found 76 species of freshwater fish, mostly riverine species (Appendix A). The species composition was dominated by carps (31 species, contributing 59.9% by weight), catfishes (14 species, contributing 20.6% by weight), murrels (4 species, contributing 7.0% by weight) and other species (27 species, contributing 19.50% by weight). The average standing crop of fish caught by rotenone sampling was 117.50 kg/ha.

The subsistence fisheries - the only type prior to damming the Nam Pong River - was carried out by part-time fishermen, mostly farmers. They fished rivers, streams, lakes, canals and paddy fields. Although fish were abundant at certain times of the year, their distribution pattern did not allow intensive fishing. The fishing season in this region more or less coincides with the rainy season, starting in May or June and ending in December or January when the paddy fields, lakes and most of the natural water bodies dry up. During the dry season only a few farmers keep catching fish in the rivers and other remaining natural water bodies.

3. THE NAM PONG RIVER DEVELOPMENT PROJECT

The Nam Pong river project is located at Pong Neeb, about 50 km northwest of Khon Kaen town. It is a multipurpose project, serving the interest of hydropower generation, irrigation, fisheries enhancement, flood control, and recreation. The project consists of the Ubolratana Dam and power plant, a diversion dam at Nong Wai, and irrigation canals to be built on both banks of the Nam Pong River. The Nam Pong Resettlement Scheme, located about 36 km north of Khon Kaen town, and the Non Sang Resettlement Scheme located some 70 km northwest of Khon Kaen town are parts of the project (Fig. 3).

The preliminary investigtion and feasibility studies of the project were completed in 1959. The construction of the Ubolratana Dam was carried out from 1964 to 1965. The power plant was officially inaugurated on 14 March 1966.

3.1 Ubolratana Dam and hydropower plant

The Ubolratana Dam was constructed across the Nam Pong River at Pong Neeb, 50 km northwest of Khon Kaen town. The dam site is at the gorge where rock is dense and massive enough to resist the weight of the dam and the water pressure. Both sides of the river upstream of the dam are encircled with mountains, namely Phu Pan and Phu Pan Kam. The resulting reservoir contains 2,550 million m^3 of water, and at full supply level it covers an area of 410 km^2. The dam type is rockfill with clay core, 800 m long at the crest, 32 m high at the maximum section. The thickness at the maximum section is 120 m at the dam base and 6 m at the crest.

The spillway is located on the right abutment. Each of the four overflows is 14.50 m wide. These overflows are capable of discharging 2,500 m^3/sec. The radial gates are 19.5 m wide by 6 m high each.

The power plant is located on the left abutment. It is a semi-outdoor, reinforced, concrete building. Inside this building are 3 Kaplan type turbo-generating units. Each unit has a 8.3 MW generator. The averge annual energy production is 65 million kwh.

Three penstocks 4.5 m in diameter are present. The intake water level is at 167.41 m MSL. The possible maximum operating head, or drop from the surface of the reservoir to the river immediately downstream of the power plant is 18.5 m.

The energy generated from the Ubolratana power plant is distributed to 8 provinces in the northeast, namely Khon Kaen, Udon Thani, Nong Khai, Kalasin, Maha Sarakham, Roi-et, Chaiyaphum and Nakhon Ratchasima. The distribution system comprises 115 kv transmission lines interconnecting 6 sub-stations located at Khon Kaen, Udon Thani, Phol, Maha Sarakham, Nakhon Ratchasima and Nong Khai.

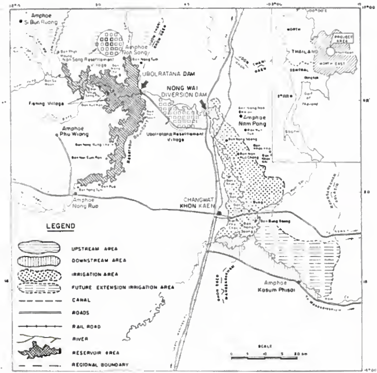


Figure 3. The Nam Pong River Development Project showing the dam site, reservoir, resettlement and irrigation areas

3.2 Nong Wai irrigation system

The Nong Wai irrigation system was designed for 42,287 ha (264,292 rai) of land which was limited to rainfed cropping in the past. Under the irrigation scheme, either additional rice crops or other types of cultivated products are feasible. The construction of Nong Wai diversion dam and other engineering works were completed in 1967. The irrigation system on the right bank of the Nam Pong River was completed in 1982, comprising 47 km of main canal, 80 km of laterals and 61 km of sublaterals, covering an area of 7,340 ha. The left bank was developed in two phases. The first phase was completed in 1979, comprising 40 km of main canals, 55 km of laterals and 60 km of sublaterals, covering an area of 9,860 ha. The second phase comprises of 43 km of main canals, 190 km of laterals and 197 km of sublaterals, covering the area of 22,045 ha. By the end of 1982, the main canal was completed together with 79 km of laterals and 82 km of sublaterals, covering an area of 7,340 ha. The rest is under construction and expected to be completed by the end of 1985.

The Nong Wai irrigation system will provide enough water for agricultural purposes. The cultivation practices in the area would shift from the rainy season single rice crop production to throughout-the-year rice crop production. Also by introducing cultivation of upland crops, which secure a higher earning rate, this plan is envisaged to improve the management of agriculture and to increase the profitability of agricultural production.

3.3 Resettlement

The development of the resettlement areas has been underway since 1964 for the benefit of the farmers who lost their land to the Ubolratana reservoir and to a few farmers who had moved from other places and needed land for farming. The displaced population was of the order of 4,000 families or around 20,000 persons. They have been resettled to Nam Pong and Non Sang, which are 36 km and 70 km distant from Khon Kaen town.

4. UBOLRATANA RESERVOIR, A NEW FISHERY RESOURCE

Prior to the completion of the Ubolratana Dam, the Department of Fisheries sent a study team to investigate the fishery status in the proposed inundated area. However, due to staff and budget limitations, only information on ichthyofauna was collected during the study (Sidthimunka et al., 1968). As mentioned already above, they recorded 76 species of freshwater fishes from the area (Appendix A).

4.1 Physico-chemical properties of impounded water

Surface water temperature is closely related to atmospheric temperature fluctuations. The water temperature exhibits three typical profiles which characterize the cold season, the transition, and the hot season. During the cold season, water temperature profile is usually uniform with slight variations in the top layer during the day and night. In the transition period from the cold to hot season, the water temperature in the top layer increases and a thermocline forms (Srisuwantaj, 1970; Jindarojana et al., 1979); this is followed by a thorough mixing during the hot and rainy seasons.

Dissolved oxygen (DO) in the reservoir water is mainly supplied by photosynthesis and agitation. Photosynthesis is predominant when the water is clear, while the agitation is more important during windy and stormy weather when water turns turbid which reduces the photosynthesis. The depletion of DO is caused by the decomposition of organic matter in the water and in the sediment. The average annual sediment inflow into the Ubolratana reservoir is estimated 2 million tons (Jindarojana et al., 1979). Almost all sediment is retained in the reservoir. Large particles are deposited near the point of the inflow, small particles (0.2 mm) are found in the middle portion, and very fine particles are found in the lower portion of the reservoir near the dam.

Concentrations of N,P and K are low. These elements are both dissolved and bound with sediments.

The quality of water in different areas of the reservoir slightly varies in terms of organic constituents. The water in the upstream part usually contains higher concentration of suspended materials than the middle and lower parts of the reservoir. The mean electric conductivity of the reservoir water is around 80 micromhos/cm during floods and 150 micromhos/cm during the dry season. The pH of impounded water is slightly above 7. However, it may rise above 8 during the dry season. The impounded water usually contains high concentrations of coliform bacteria which enter the reservoir from the fishing villages scattered along the shoreline.

The tailwater quality is similar to that of the reservoir in front of the penstock intake, and since the water is usually drawn deep below water surface, with the intake at 162 m MSL, the dissolved oxygen in the discharged water is usually low or depleted. Along the flow path downstream, DO is continuously increased by stream reaeration. At the Nong Wai diversion dam the water is aerated vigorously and becomes saturated with dissolved oxygen. DO in the water downstream of the diversion dam is usually more than 6 mg/l throughout the year.

The pH of the Nam Pong downstream of the dam is around 7. Water turbidity, low at the dam tailwater, gradually increases as it receives sediments from scouring and during the rains the mud from river banks. The water is usually poor in plant nutrients. Potassium is the only plant nutrient available in relative abundance. The water has a low concentration of organic substances. The BOD of the water is low throughout the year, even though the COD is high. While the numbers of coliforms and total bacteria in the water below the dam are usually low, they increase gradually with distance due to the faecal pollution from the river banks.

4.2 Plankton

The primary production of the Ubolratana reservoir fluctuates seasonally, being moderately high in summer, relatively low in rainy season and increasing again after that. Jaiyen et al., (1980) identified 26 species of plankton, i.e. algae which are dominated by *Melosira*, *Microcystis*, *Pediastrum*, and *Ceratium*. Their standing crop is generally higher in the central area of the reservoir than at the inflow areas, and it is the highest in May.

Copepods are the most abundant zooplankton, followed by cladocerans, rotifers and protozoans. The highest standing crop of zooplankton is found in the inflow areas in April. The blue-green algae were the commonest nanoplankton. They have a similar pattern of occurrence as that of the other phytoplankton. Filamentous blue-green algae, bryozoans and protozoans are the most common periphyton found on the submerged trees from the water surface down to 3 m depth.

4.3 Aquatic macrophytes

Eighteen species of aquatic macrophytes were found in the Ubolratana reservoir in 1980 (Varikul *et al.*, 1980) as compared to 35 species recorded during 1981-82 (Watanadilokgul and Sribanjaem, 1982), (Table 1). Almost all were in the littoral, at a depth of one meter or less, except *Potamogeton*. The witchgrass (*Panicum*) was the most abundant species, followed by the Florida elodea (*Hydrilla verticillata*) and pond weed (*Potamogeton*). *Panicum* and *Potamogeton* dominated during the dry period (November to May), and disappeared in July, as water level reached its peak. The Florida elodea increased during the low water level period, and then disappeared in the early rainy season (May to June) due to a high turbidity (Varikul *et al.*, 1980). The aquatic macrophyte invertebrate fauna is represented predominantly by insects. The mean number and mean weight per m^2 of invertebrates associatd with aquatic macrophytes were 3,034 and 1.48 gm respectively.

4.4 Benthic fauna

Annelids, chironomids, chaoborids, oligochaetes and molluscs dominated the benthos which mostly concentrated down to 6 m depth. The others recorded were ceratopogonids, ostracods, *Caenis* and some other insect larvae. Their abundance varied from area to area, but was generally higher in open-water than in the inlet areas. The richest area was 2 m depth, but the 0.5 m to 3.5 m depths were generally productive.

4.5 Fish species composition

Changes of fish species composition were observed within one year of the impoundment. Only 52 species were collected by the rotenone treatment as, compared to 76 species prior to impoundment. Of these, 44 species were the same as in the river, and 8 species were new records. The samples were dominated by carnivorous species of murrels (*Channa*) which comprised 34.8% by weight compared to 24.1% for carps, 1.19 for catfish, and 29.2% of miscellaneous species (Bhukaswan and Pholprasith, 1977).

Further investigations with rotenone sampling showed fluctuations in fish species composition: 76 species in 1965, 52 in 1966, 62 in 1967, 73 in 1969, 58 in 1970, 67 in 1971, 68 in 1973 (Bhukaswan and Pholprasith, 1977), and only 37 species in 1981 and 1982 (Nookour and Pawapootanon, 1982) as shown in Appendix A. The following species eventually disappeared from the impoundment: *Rasbora heteromorpha*; *Barilius guttatus*, *Labeo bicolor*, *Crossocheilus reba*, *Mekongina erythrospila*, *Botia beauforti*, *Pteropangasius cultratus*, *Bagarius bagarius*, and *Trichogaster microlepis*. Several species became dominant such as *Pristolepis fasciatus*, *Cyclocheilichthys apogon*, *Trichogaster trichopterus*, *Osteochilus hasselti*, *Notopterus notopterus*, *Hampala dispar*, *Puntius leiacanthus* and *Channa striata*. Some species were found only in post impoundment samples such as *Mastacembelus circumcinctus*, *Rasbora borapetensis*, *Puntius viehoeveri*, *Osteochilus duostigma*, *Labiobarbus lineatus*, *Clarias macrocephalus*, *Mystus atrifasciatus* and *Chanda siamensis*. The differences were presumed due either to insufficiency of the sampling method (rotenone) and sample collecting and/or due to accidental infiltration from other areas.

Table 1

Aquatic macrophytes in Ubolratana reservoir,
Khon Kaen, Thailand, during 1979-83

Floating	Submersed	Emergent	
Eichhornia crassipes*	Hydrilla verticillata*	Jussiaea linifolia	Monocharia vaginalis
Pistia stratiotes*	Potamogeton sp.*	J. repens*	Leersia hexandra
Salvinia cucullata*	Blyxa echinosperma	Polygonum tomentosum*	Paspalum scorbiculatum
Azolla pinneta*	Najas graminea*	Colocasia esculenta	Hygrorrhiza aristata
Lemna minor	N. indica*	Scirpus grossus	Imperata cylindrica
Trapa guadrispinosa	Utricularia flexuosa*	S. articulatus	Arundo sp.
	Ceratophyllum demersum*	Cyperus rotundus	Alternanthera amphixoides*
	Nitella sp.*	Fimbristylis miliacea	Mimulus orbicularis
	Chara sp.	Scleria poaeformis	Marsilea crenata*
		Neptunia oleracea	Ipomoea aquatica*
			Panicum sp.

* Reported by Varikul et al., (1980)

4.6 Fish standing crop

The estimation of standing crop of the Ubolratana reservoir was based on data collected from rotenone sampling, which was the only source of information available. Although this method gives only a rough estimate of the fish yield, it is still a useful tool for assessing the annual changes in fish stock. As known for other reservoirs, the fish standing crop of the Ubolratana also rapidly increased during the first two years of impoundment. Thereafter, it started decreasing to reach a minimum in 1970. Afterwards, there has been an increase with the maximum standing crop recorded in 1983 (Table 2).

The commercial catches per unit surface area have shown year to year fluctuations, but no substantial long-term changes have taken place. The maximum was recorded in 1976 which was approximately 3 times greater than that of the second year after impoundment (Table 2).

5. FISHERY DEVELOPMENT IN THE UBOLRATANA RESERVOIR

5.1 The fishermen

Fisheries in Ubolratana reservoir started shortly after the establishment of the impoundment in 1965, when farmers living in villages nearby found fishing the reservoir a rewarding activity. The first fishermen were those farmers who lost their land by inundation and squatted around on whatever land was left, sometimes with relatives, instead of moving elsewhere. The unusual abundance of fish during the first few years together with the relatively low number of fishermen resulted in an exceptionally good catch per person.

These people were soon followed by others, mostly rice farmers, who became attracted by the high income from fishing. The nearby farmers were beginning to move into the reservoir for fishing on a permanent basis. This process was made easy by the fact that migration has been part of the northeast culture and most of the farmers have had experience in fishing with one kind of fishing gear or more. Due to no restriction on entry to the reservoir margin where land is publicly owned, new opportunity provided by fishing was soon exploited to the utmost.

The number of fishermen operating in this reservoir have continuously increased from 268 in 1966 (Sidthimunka et al., 1972), to 3,556 in 1975 (Bhukaswan and Pholprasith, 1977), and to 5,628 in 1978 (Suetrong et al., 1979).

5.2 Fishing gears

Fishing in the Ubolratana reservoir is permitted 24 hours a day throughout the year. The commercial catches were recorded since the beginning of commercial landings in the second half of 1966. Records of fish landings were collected at six landing centres. They are at Tha Rua Ubolratana, Ban Poh-Tak, Ban Nong Tum, Ban Wang Hin Sa, in Khon Kaen province and at Ban Non Sang, Udon Thani province (Fig. 4). Landing statistics were recorded on daily basis at Tha Rua Ubolratana and at Ban Poh-Tak, the others were collected from random sampling done every two weeks. Total weight of fresh and processed fish (smoked, salted and fermented fish) were recorded. Those of processed fish were converted into weight of fresh fish by multiplying with a specific constant. The ratios used for converting weight of processed fish to weight of fresh

Table 2

Comparison of standing crop (rotenone sampling) and commercial catch per hectare and changes in
major economic fish groups during 1965-1983, Ubolratana reservoir, Khon Kaen, Thailand. (1965 - pre-impoundment)

Fish yield	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Standing crop																			
Weight (kg/ha)	117.48	177.66	158.10	109.35	94.50	64.32	76.02	-	114.00	-	-	-	-	-	-	-	178.75	171.88	-
Fish grouping (%)																			
Carp	55.90	24.10	21.58	-	51.18	18.72	21.40	-	28.80	-	-	-	-	-	-	-	75.80	71.60	-
Catfish	20.60	34.80	3.01	-	1.50	2.65	2.80	-	7.30	-	-	-	-	-	-	-	13.80	6.40	-
Murrel	7.00	11.90	24.86	-	14.02	25.48	19.81	-	18.30	-	-	-	-	-	-	-	1.50	7.70	-
Miscellaneous	16.50	29.20	50.55	-	33.30	53.15	55.99	-	45.60	-	-	-	-	-	-	-	9.00	14.30	-
Commercial catch																			
Weight (kg/ha)	-	12.00*	22.86	30.04	52.52	38.77	54.15	42.87	49.26	61.94	36.95	63.04	55.92	46.62	37.25	32.65	49.53	37.06	58.83
Fish grouping (%)																			
Carp	-	-	-	-	48.07	65.86	71.92	70.55	73.54	71.13	72.02	73.77	72.28	73.66	75.34	63.95	71.76	61.85	75.50
Catfish	-	-	-	-	11.22	9.11	9.97	9.80	5.88	1.40	1.83	2.34	3.71	8.21	13.39	12.03	11.66	10.39	5.51
Murrel	-	-	-	-	19.90	7.38	4.01	2.58	2.73	1.53	1.53	1.48	1.22	1.54	1.48	0.80	0.56	0.45	1.29
Miscellaneous	-	-	-	-	29.81	17.65	14.10	17.07	17.85	25.94	24.62	22.41	22.79	16.59	9.79	23.22	16.02	27.31	17.70

* Only 6 months commercial catch data available

fish are 1:3, 1:2 and 1:0.8 for smoked fish, salted fish, and fermented fish respectively. The fish were landed as follows: 60% at Tha Rua Ubolratana, 20% at Ban Wang Hin Sa, 10% at Ban Poh-Tak, 5% at Ban Nong Tum, 3% at Ban Non Sang, and 2% at Ban Fah-Liam (Ubolratana Reservoir Fisheries Research Station, 1984).

The commercial catches have fluctuated from year to year. High fish catches were recorded in 1969, 1971, 1974, 1976, 1977 and 1983, while low catches were recorded in 1975, 1979, 1980 and 1982 (Table 3). Records of monthly catches show seasonal fluctuations. Catches usually increase during the low water-level period (November to April).

Cyprinids have dominated the catch, contributing 69.41% (15 year average) to annual fish landings since 1969 (Table 2). The major fish species in the commercial catches were Cirrhinus jullieni, Puntius spp. (mainly Puntius lieacanthus), Corica goniognathus, Puntioplites proctozysron, Osteochilus hasselti, and Morulius chrysophekadion respectively. These contributed 88.21% to the annual catch in 1976. Over the last 15 years these six major species formed 79.65% of the total catch (Table 4).

5.4 Fish stocking

Fish stocking programme has been practised in the Ubolratana reservoir since the filling period. The purpose of stocking is to provide more food fish by utilizing food resources not used by the local fish species, and to control aquatic vegetation in the impoundment. For this, the grass carp (Ctenopharyngodon idella), Thai silver carp (Puntius gonionotus), and the sepat-siam (Trichogaster pectoralis) were introduced immediately after the dam was closed. Plankton feeders such as the bighead carp (Aristichthys nobilis), and silver carp (Cirrhinus molitorella) were also stocked. Pangasius sutchi and Probarbus jullieni were introduced to feed on benthic organisms and molluscs. Later, several other species were added, and so far 19 species have been stocked, totalling 5.8 million fingerlings (Table 5).

It is difficult to evaluate the success or failure of stocking programme due to insufficient data on recapture. Several species of stocked fish were indigenous species which were found living in the inundated areas prior to the impoundment, thus it is impossible to identify which one is native or additionally stocked. The introduced sepat-siam (Trichogaster pectoralis) dominated the yield particularly during 1969-1972, but the other introduced and stocked species have not yet been found in significant numbers.

However, some introduced species have shown a very good growth rate. For example, the grass carp reached 12.40 kg in 2 years; silver carp 5.8 kg in one year; rohu (Labeo rohita), Cyclocheilichthys enoplos, and Datnoides microlepis reached 5.40 kg, 2.60 kg, and 2.6 kg respectively in 3 years, and Probarbus jullieni a weight of 10.70 kg in 4 years (Bhukaswan and Pholprasith, 1977).

5.5 Aquaculture development

Fish raising programme was launched in Khon Kaen province in 1954 when a fisheries station was established in this province. Fish are raised in ponds for household consumption, and the excess of fish produced is sold to neighbours. Most of these fish ponds are small. Rice-cum fish is also

Table 3

Total commercial catch from the Ubolratana reservoir,
Khon Kaen, Thailand, during 1966-1983 (weight in kilograms)

Year	Months												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1966	-	-	-	-	-	-	103,429	133,446	134,287	60,084	26,554	20,514	*478,314
1967	21,084	15,812	25,278	28,387	41,800	69,519	115,784	176,419	190,214	114,931	62,244	52,881	914,353
1968	52,425	53,060	65,205	85,328	105,218	137,911	141,650	119,958	126,271	124,172	94,425	96,007	1,201,630
1969	114,092	206,992	188,857	238,064	326,920	225,798	228,701	140,856	167,035	97,062	69,464	96,903	2,100,744
1970	89,712	92,416	108,281	107,447	166,453	196,163	159,277	185,242	169,067	109,215	77,606	88,956	1,550,835
1971	106,455	101,341	134,995	134,700	222,078	290.859	317,593	294,841	192,069	167,722	110,093	93,085	2,165,831
1972	119,283	130,316	130,926	107,980	161,404	178,295	121,660	183,330	172,395	204,313	114,910	89,989	1,714,801
1973	84,998	83,467	108,136	86,138	114,097	211,116	211,433	169,657	264,918	219,394	210,263	206,829	1,970,446
1974	228,459	154,265	172,307	223,249	210,259	250,732	201,267	288,203	230,561	223,959	150,431	143,809	2,477,492
1975	119,017	137,183	103,434	103,893	96,755	114,454	189,067	124,665	161,519	135,934	104,515	87,736	1,478,172
1976	126,644	149,096	153,428	160,478	212,062	300,656	267,313	289,561	285,841	295,751	134,493	146,168	2,521,491
1977	148,721	119,817	188,464	204,704	251,817	166,141	176,227	263,852	178,539	208,084	119,758	210,798	2,236,922
1978	125,671	93,472	203,329	215,802	158,880	183,000	293,936	177,365	124,793	127,530	90,203	70,782	1,864,763
1979	75,852	86,321	92,913	112,408	211,208	158,302	153,150	160,466	171,449	170,370	50,217	47,316	1,489,972
1980	31,608	52,861	70,712	35,099	134,994	174,154	96,843	144,700	204,625	143,258	95,158	121,981	1,305,993
1981	124,656	135,850	152,535	234,708	236,521	175,549	245,516	158,548	172,080	225,444	86,238	33,392	1,981,037
1982	55,533	60,078	95,756	84,453	118,302	147,681	123,959	134,062	223,702	100,985	202,105	135,621	1,482,237
1983	134,280	158,102	143,932	143,663	218,617	293,958	255,909	253,978	192,370	160,299	115,563	122,547	2,193,218
Average	103,441	107,673	125,793	135,677	175,729	192,605	189,040	188,858	186,763	160,471	106,347	103,629	1,802,937

* Total for six months only

Table 4

Major fish species in commercial catches from the Ubolratana reservoir,
Khon Kaen, Thailand, during 1969-1983 (metric ton)

Species	Annual Catch															Average
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	
Cirrhinus jullieni	21.8	71.4	403.6	323.7	171.7	520.4	209.0	558.5	611.4	551.1	547.6	338.1	851.7	348.5	818.0	423.10
Puntius spp.	-	631.3	502.1	490.8	401.4	496.6	368.7	497.1	392.6	302.3	296.6	261.7	327.2	290.9	441.8	407.22
Corica goniognathus	-	-	-	-	-	149.5	214.7	396.9	357.7	138.3	45.9	235.4	251.7	333.6	300.1	252.31
Puntioplites proctozysron	-	36.0	38.8	39.9	292.3	503.4	232.6	502.7	353.4	256.7	173.3	142.1	132.7	165.8	32.0	207.26
Osteochilus hasselti	281.9	80.8	237.9	134.0	126.2	161.8	85.2	132.3	122.5	101.4	60.8	54.6	59.9	29.4	59.2	115.19
Morulius chrysophekadion	137.7	62.9	112.5	80.7	176.7	136.5	141.0	136.6	75.2	86.6	27.3	16.2	21.9	46.4	32.0	110.02
Total*	435.4 (2100.7)	882.4 (1550.8)	1294.9 (2165.8)	1068.3 (1714.8)	1168.3 (1970.4)	1968.2 (2477.5)	1251.2 (1478.2)	2224.1 (2521.5)	1912.8 (2236.9)	1436.4 (1864.8)	1151.5 (1490.0)	1048.1 (1306.0)	1645.1 (1981.0)	1214.6 (1482.2)	1683.1 (2193.2)	1515.10 (1902.25)
Percentage in annual catch	20.73	56.90	59.79	62.30	50.29	79.44	84.64	88.21	85.81	77.03	77.28	80.25	83.04	81.95	76.74	79.65

* Numbers in parentheses represent the total annual catch

Table 5

Species and numbers of fish fingerlings stocked in the Ubolratana Reservoir,
Khon Kaen, Thailand, during 1968–1981

Species	Year														Total
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	
Trichogaster pectoralis	20,000	-	-	-	-	-	-	-	-	-	-	-	-	-	20,000
Aristichthys nobilis	-	6,500	-	7,000	-	-	-	30,000	6,000	-	-	-	-	-	49,500
Cirrhinus molitorella	-	10,300	13,700	5,000	-	19,500	-	-	-	-	-	-	-	-	48,500
Ctenopharyngodon idella	1,000	3,400	-	-	-	-	-	-	-	-	-	-	-	-	4,400
Hypophthalmichthys molitrix	-	-	20,000	5,000	-	19,000	-	-	-	-	-	-	-	-	44,000
Ostnoides microlepis	-	-	-	-	2,850	-	-	-	-	-	-	-	-	-	2,850
Cyclocheilichthys enoplos	-	-	-	-	1,190	1,400	-	-	-	-	-	-	-	-	2,590
Labeo rohita	-	-	-	-	-	40,000	10,000	35,000	87,300	70,000	686,100	425,000	104,050	-	1,457,450
Notopterus chitala	-	-	-	200	-	-	-	-	-	-	-	-	-	-	200
Pangasius sanitwongsei	-	-	-	-	-	3,800	-	-	-	-	-	-	-	-	3,800
P. sutchi	-	-	-	8,400	-	-	-	-	-	10,000	50	149,000	-	-	167,450
Oreochromis niloticus	-	-	-	-	-	-	-	-	-	-	-	-	-	35,400	35,400
Puntius gonionotus	600	-	-	-	-	-	-	-	-	50,000	1,913,300	1,076,900	57,900	45,300	3,144,000
Osteochilus melanopleura	-	-	-	-	-	-	-	-	-	-	1,850	-	-	-	1,850
Puntioplites proctozysron	-	-	-	-	-	-	-	-	-	340,000	141,540	-	-	-	481,540
Mystus nebulus	-	-	-	-	-	-	-	4,500	-	-	-	-	-	-	4,500
Labeo berhi	-	-	-	-	-	-	-	-	-	-	-	25,000	-	-	25,000
Cyprinus carpio	-	-	-	-	-	-	-	-	-	-	-	-	-	101,700	101,700
Probarbus jullieni	-	-	-	10,200	-	2,800	30,000	19,870	18,800	55,000	104,000	-	-	-	240,670
Total	21,600	20,200	33,700	35,800	4,040	86,500	40,000	89,370	112,100	525,000	2,846,840	1,675,900	161,950	182,400	5,835,400

practised in the irrigated areas. Favourable fish species being raised are Oreochromis niloticus, Cyprinus carpio, and Puntius gonionotus. Others include Labeo rohita, Channa striata, Clarias batrachus and Pangasius sutchi. Statistics in 1982 showed 4,336 fish ponds with a total surface area of 665 ha, and 437 ha of paddy fields to be used for fish culture in Khon Kaen province (Table 6).

Besides raising fish in ponds and paddy fields, fish are also being stocked in various water bodies throughout the basin in order to provide a better fishery resources to the rural inhabitants. In 1983, a total of 6,443,800 fish fingerlings were stocked in 370 water bodies covering a surface area of 46,690 ha (291,815 rai). Stocked fish were Oreochromis niloticus, Cyprinus carpio, Puntius gonionotus, Labeo rohita, Aristichthys nobilis, Cirrhinus molitorella and Ctenopharyngodon idella.

With the development of Nong Wai irrigation project, the Fisheries Department has introduced fish raising and fish stocking programmes into Nong Wai irrigated area since 1978. These programmes are well established, with 183 fish ponds (31 ha) and 96 paddy fields (65 ha) being used for fish culture, and 16 impoundments (230 ha) stocked with 604,300 fish fingerling (5-7.5 cm long) in 1983.

The fish yield derived from aquaculture in Khon Kaen province has been increasing since 1975. It was 280 metric tons in 1975, 551 metric tons in 1978 and 1,134 metric tons in 1982 (Table 6). The average annual fish yield in the impoundments following the stocking programme was improved from around 90 kg/ha to 300 kg/ha.

6. SOCIO-ECONOMIC ASPECTS OF THE FISHERMEN

The Mekong Secretariat conducted the first study on socio-economic aspects of the fishermen in Ubolratana reservoir in 1971 (Mekong Secretariat, 1972). Six years later, the second study was made during June 1977 to September 1978 as part of the Nam Pong Environmental Management Research Project (Suetrong et al., 1979). This study covered three major areas of the Nam Pong River Basin development project, the lake-side villages, the Nong Wai irrigation area, and the resettlement areas. The investigation was designed for collecting socio-economic information on fishery sector which is considered necessary to the development and management of the fisheries in Ubolratana reservoir. Details of collected data are elaborated in Table 7.

6.1 Social aspects

Every adult farmer in Thailand regardless of sex knows how to catch fish. Prior to the development of the Nam Pong river project, fish were caught mainly for household consumption, with only a few being for sale, particularly in Khon Kaen province. After the Ubolratana Dam was closed, farmers living in the villages nearby found it advantageous to fish the new reservoir. Their catches were good and they had a good income from fishing due to the high fish production during the first few years. At that time there were also relatively few fishermen in the area. Soon, however, there was an influx of others, mostly rice farmers who were attracted by better prospects of fishing instead of rice farming.

A survey around Ubolratana reservoir in 1971 indicated that 88.4% of the fishermen were previously engaged in rice farming, 1.6% in upland farming (mostly kenaf), 6.1% were wage labourers, and only 1.8% were

Table 6

Number of fish farms, areas and total fish production in
Khon Kaen Province, during 1975 - 1982

Categories	1975	1976	1977	1978	1979	1980	1981	1982
Number of fish farms								
- fish ponds	1,752	2,411	2,646	3,396	3,116	3,183	2,622	4,336
- Paddy fields	417	479	440	424	404	375	357	608
Sub-total	2,169	2,890	3,086	3,820	3,520	3,558	2,979	4,944
Area of fish farm (ha)								
- fish ponds	166	223	244	382	457	487	432	665
- paddy fields	253	298	282	296	335	294	256	437
Sub-total	419	521	526	678	892	781	688	1,105
Fish production (metric ton)								
- pond culture	220	277	302	440	420	417	460	740
- paddy field culture	61	55	74	111	114	82	103	394
Sub-total	281	332	376	551	534	499	563	1,134
Value (1,000 baht)*								
- pond culture	2,796	3,773	4,961	7,032	8,724	9,467	13,423	18,156
- paddy field culture	887	866	1,321	1,759	2,414	2,153	3,027	9,678
Sub-total	3,683	4,639	6,282	8,791	11,138	11,610	16,450	27,834

* 1 U.S. dollar = 23 baht (1983)

Table 7

Summary information on a socio-economic survey of the people living in the Nam Pong River Basin during 1977-1978

Categories	Nong Wai Irrigation area	Nam Pong Resettlement	Lake-side villages
Number of households	9 230.0	900.0	7 408.0
Average household size	6.3	6.3	6.5
Land-holding (percentage)	90.5	83.5	83.0
Crop growing households (percentage)	95.9	100.0	80.6
Cultivated area per household (ha)	3.10	2.35	2.48
Average yield (ton/ha)			
- paddy	2.04	1.0	1.21
- cassava	9.41	9.37	5.06
Annual gross income from crop/household (baht)	12 757.80	7 383.0	5 770.0
Percentage of households raising livestock and poultry	100.0	100.0	100.0
Annual gross income from livestock/household (baht)	1 938.0	1 157.0	1 902.0
Percentage of fishing families	79.1	25.4	75.5
Annual gross value of fish catches/household (baht)	735.40	260.0	4 435.0
Annual income from fish sale per household (baht)	148.80	101.0	3 536.0
Annual gross income from other sources (baht)	3 788.0	1 672.0	2 952.0
Annual gross income per household (baht)	19 219.20	10 472.0	15 059.0
Annual expenditure per household (baht)	7 475.40	8 255.0	6 760.0
Annual net income per household (baht)	11 743.80	2 217.0	8 299.0

Adapted from: Suetrong et al., (1979)

fishing for a living before moving to the lakeshore. The rest (2.1%) were unidentified (Mekong Secretariat, 1972). Most of the farmers who changed their occupation to fishing were mainly those who lived in the same vicinity for some time before the reservoir was established. About 40% were moved in from elsewhere. About half of the latter were from other parts of Khon Kaen and Udon Thani, the provinces at the border of which the reservoir is located. The other one-third were from other provinces in the northeast and the rest were from other regions of the country.

The average size of a fisherman family increased from 6.0 to 6.5 persons. The fishermen population was classified into young independents (0-14 years), work-force (15-64 years), and old dependents (over 65 years) representing 43.0%, 53.9% and 3.1% respectively. There was a higher percentage of females over males for all age groups, giving an average of 52.4% females to 47.6 males. About two-thirds of the population were married.

The majority of the population (74.7%) had some education. Primary school Grade 4 was the highest level reached by most, representing 68.9%. Primary school Grades 5-7 education had only been reached by 3.1% and secondary education by 2.0%. A mere 0.2% went to college. It was found that 74.9% of the economically active group (work-force) were farmers by occupation. Fishing (6.4%) and working as labourers (4.3%) were the second and third most common occupations. Merchants and government civil servants made up less than 2%.

Dwelling units in the fishing villages belonged to three types, permanent (67.9%), semi-permanent (27.7%) and temporary (4.4%). The permanent type dwellings, mostly native style of two storey house with open ground floor, were generally owned by large, long settled well-off families. The other two types were owned by those who had moved in after the construction of the dam. In general, a house had 2-3 rooms.

Rice is the single major crop grown by farming households (60.9%). The others grow rice and other crops, 15.8% grow rice and kenaf, 8.5% rice and cassava, and 8.0% rice, fruits and vegetables. Other crops are grown in limited quantities. The gross production value of rice alone accounted for 89% of the total gross value of all crops grown. Kenaf and cassava accounted for a further 4.6% and 2.5% respectively.

6.2 Economic aspects of fishing operations

Fishing operation as practised in Ubolratana reservoir involves only one or two persons in each family. The operation is simple and consists of setting gill-nets. Another method is light attraction of the freshwater sardine-like Corica goniognathus during moonless nights. Other methods of fishing involve the use of cast-nets, hooks and line, lift-nets, bamboo traps, and some others to catch fish. The results of this fishing is largely insignificant in terms of the number of persons involved or the quantity of fish caught compared to those from fixed gill-nets.

A sampling survey of the type and number of fishing gears owned by fishermen households in selected villages of the lakeside was conducted during the socio-economic studies in 1977-78 (Suetrong et al., 1979). It was found that gill-nets were owned by 77.6% of the fishing households, averaging 4.7 nets per fishing household (Table 8). 40.3% of the households possessed hook and long-line. Lift-nets and cast-nets were owned by only 8.6% and 13.4% of the fishing household respectively. The

Table 8

Type and number of fishing gears owned by fishermen households in the sample villages in the lake-side area (from Suetrong *et al.*, 1979)

Fishing gears	Number of fishing gears				Households with gear		Average number/household
	Nong Rua	Phu Wiang	Non Sang	Si Bun Ruang	Number	Percentage of	
					(All households 397)		
Rowing boats	31	78	94	78	252	63.5	0.7
Motor boats	20	28	16	10	74	18.6	0.2
Gill-nets	300	664	583	325	308	77.6	4.7
Hooks	2,542	11,799	9,224	4,792	100	40.3	79.9
Cast-nets	16	5	66	1	53	13.4	0.2
Lift-nets	3	0	11	38	34	8.6	0.1

Table 9

Total value of fish caught and sold in the sample villages in the Nong Wai irrigation area, the Nam Pong resettlement and the lake-side villages during 1977-1978 (from Suetrong *et al.*, 1979)

Categories	Nong Wai irrigation area	Nam Pong Resettlement	Lake-side villages
Fish caught			
Number of household	179	16	397
Value in baht	194,383	16,350	2,333,061
Average per household (baht)	1,086	1,022	5,876.7
Fish sold			
Number of household	58	4	397
Value in baht	39,560	6,350	1,860,144
Sales per household (baht)	682	1,587.5	4,685.5

possession of a boat in this area also indicated that one is seriously involved in the pursuit of fishing. Unmotorized boats were owned by 53.5% of the fishing households, and motorized boats by 18.6%. 17.9% of the fishing households did not own boats which indicates that they engaged mainly in farming.

Capital investment in fisheries in Ubolratana reservoir was rather small. It was estimated to be on the average 594.56 baht per household in 1971 (Mekong Secretariat, 1972), and increased to 949.10 baht in 1978 (Suetrong et al., 1979). Although the average amount of capital investment was small, there were still some fishermen who did not have enough cash to invest. In case he could not afford to pay the total cost in cash, he would pay for part of it leaving the balance to be paid by installments. In some cases when the fisherman did not have any cash he would rely entirely on credit, in which case he would normally be obliged to sell fish only to his creditor, sometimes at a price slightly lower than that prevailing.

Fishing was an additional source of income for the 179 households in the sample villages in Nong Wai irrigation area. The total value of annual fish caught was 194,383 baht or 1,086 baht per fishing household. Of this amount, 80% was used for home consumption and the balance sold or bartered (Table 9).

Sixteen households in the sample villages in the resettlement area, a quarter of the total number of sample households, enjoyed some income from fishing. The fish they caught was valued at 16,350 baht, averaging 1,021.90 baht per household per annum. Only four households had fish left over from consumption for selling (Table 9).

In the lakeside area, 397 households in the sample villages engaged in fishing. The average household catch was 1,193 kg of fish annually worth 5,877 baht. Of these fish, they sold 947.3 kg (79.4% of the catch) worth 4,686 baht. The remaining 245.7 kg was consumed by the household (Tables 9 and 10).

The distribution of fish caught from Ubolratana reservoir starts daily early in the morning after fishermen return with their catch. Almost every lakeside village has one or more fishmongers who move about in motor driven boats. A fishmonger usually buys fish from fishermen who live in the same village and sells to the wholesaler at landing places, mainly at Tha Rua Ubolratana. There, the fish is sold principally to:

(a) the wholesalers who buy fresh fish for resale at retail markets;

(b) the fish processors who buy fish for fermenting, salting or smoking.

Those who buy fish for fermentation engage labourers, mostly women, to process it manually in the vicinity of the purchase area. Those who process the fish by salting and smoking buy only a few, mainly snakeheads and catfish, to process them in the backyard of their house, usually not far away from the landing place. The wholesalers occasionally arrive to buy the processed fish and take them to consumers, mainly in Khon Kaen, Udon Thani, and in the nearby provinces.

Table 10

Information on fishing, home consumption, sales, total production, prices, expenditure and profits in the sample villages in the lake-side area (from Suetrong et al., 1979)

Items	Nong Rua	Phu Wiang	Non Sang	Si Bun Ruang	Total	Percentage
Number of fishing households	58	95	158	86	397	75.5
Home consumption						
Total consumption (kgs.)	15,194.0	34,889.0	33,249.0	14,226.0	97,558.0	20.6
Average consumption per household (kgs.)	262.0	367.2	210.4	165.5	245.7	
Total value of consumption (baht)	75,440.0	118,492.0	191,495.0	87,490.0	472,917.0	20.3
Average value of comsumption per household (baht)	1,300.7	1,247.3	1,212.0	1,017.3	1,191.2	
Total sales (kgs.)	100,970.0	162,334.0	71,069.0	41,696.0	376,069.0	79.4
Average sale per household (kgs.)	1,740.8	1,708.8	449.8	484.8	947.3	
Total value of sales (baht)	478,280.0	666,459.0	456,475.0	258,930.0	1,860,144.0	79.7
Average value of sales per household (baht)	8,246.2	7,015.4	2,889.1	3,010.8	4,685.5	
Total production						
Total production (consumption plus sales) (kgs.)	116,164.0	197,223.0	104,318.0	55,922.0	473,627.0	100.0
Average production (consumption plus sales) per household (kgs.)	2,002.8	2,076.0	660.2	650.3	1,193.0	
Total value of production (baht)	553,720.0	784,951.0	647,970.0	346,420.0	2,333,061.0	100.0
Average value of production per household (baht)	9,546.9	8,262.6	4,101.1	4,028.1	5,876.7	
Price per kilogram (baht)	4.77	3.98	6.21	6.19	4.93	
Fishing expenditure						
Total expenditure (baht)	57,648.0	104,002.0	113,456.0	88,054.0	363,160.0	15.6
Average expenditure household (baht)	993.9	1,094.8	718.1	1,023.9	914.8	
Profits						
Total profits (baht)	496,072.0	680,949.0	534,514.0	285,366.0	1,969,901.0	84.4
Average profits per household (baht)	8,553.0	7,168.0	3,383.0	3,004.0	4,962.0	

7. OVERALL PROJECT COSTS AND BENEFITS

The Government of Thailand has made considerable investment in developing the Nam Pong River Basin in Khon Kaen for hydroelectric power, irrigation, fisheries, flood control and recreation. It has been argued whether this project really serves these purposes and whether it has been worth the investment. To answer this question, Miss Sangsriratanakul (1981) of Mahidol University, Bangkok, Thailand, conducted a study on evaluation and reappraisal of cost-benefit analysis for this project. In her study she summarized all costs related to the overall project development as presented in Table 11. She assumed the project life is 50 years and gave the year 1966 as the base year for economic comparison. Summations of all annual costs including those incurred prior to 1966 are made to the year 2016.

The total project cost was estimated at 6,548 million baht. It consisted of 1,022 million baht for power features and joint use facilities at the Ubolratana head-work; 1,565 million baht for irrigation system; 331 million baht for resettlement development; 1,652 million baht for foregone output from forest, and 1,979 million baht for foregone output from paddy fields.

She also demonstrated the monetary value benefits from power generation, irrigation, flood control, fisheries and recreation. All of the anticipated benefits are summarized in Table 12. The overall project benefit is estimated at 11,644 million baht, comprising 2,948 million baht from hydroelectric power, 5,651 million baht from irrigation; 1,314 million baht from flood control; 1,651 million baht from fisheries and 80 million baht from recreation.

The benefit-cost ratio estimate was based on a project life of 50 years and interest rate of 6, 8 and 10%. It gives the ratio of 1.08, 0.91 and 0.77 for discount rates of 6, 8 and 10% respectively (Table 13). The outcome indicates that the project provides negligible benefits, in other words, it is a poor investment.

8. SUMMARY AND CONCLUSIONS

Since 1959, and especially after the completion of the dam in 1965, the Government of Thailand has been developing the Nam Pong River as a multiple-use water project for generating hydroelectric power, irrigation, fisheries, navigation, and recreation. The produced electricity is distributed to 8 provinces of the northeastern Thailand, namely to Khon Kaen, Udon Thani, Kalasin, Maha Sarakam, Roi-et, Chaiyaphum and Nakhon Ratchasima. The average annual energy production is 65 million kilowatt-hours.

The irrigation system of this project is designed to provide water for agriculture on an area of 42,287 ha. By the end of 1982 about 93% was completed, with the remaining 7% to be completed by the end of 1985. Two resettlements have been established, i.e. at Nam Pong in Khon Kaen province and at Non Sang in Udon Thani province. These resettlements have 4,000 families or about 20,000 persons.

The establishment of Ubolratana reservoir has provided an ideal fishery resource to the rural inhabitants, who are mostly rice farmers. Many farmers have become fishermen and they earn more income from fishing

Copyright Material

Table 11

Summary of the cost of the Nam Pong river development project
(from Sangsriratanakul, 1981)

Year	Power and joint use facilities		Irrigation facilities				Resettlement	Total Project Cost,M฿ (1)	Forest foregone output M฿ (2)	Paddy field foregone output (3)	Total project cost M฿ (1+2+3)
			Construction costs M฿								
	Construction M฿	OM&A M฿	Main irrigation system	Nong Wai on farm	OM&A M฿	Total Cost M฿	Construction and OM&A, M฿				
1964							14.83	14.83	2.26	12.63	29.72
1965			33.78			33.78	14.83	48.61	2.46	14.31	65.38
1966	463.67	4.84	30.16			30.16	65.83	564.50	2.80	14.02	581.32
1967		5.90	54.69			54.69	5.83	66.42	2.56	4.02	73.00
1968		6.09	62.53		0.48	63.01	5.83	74.93	3.04	11.63	89.60
1969		6.33	64.59		2.01	66.60	2.92	75.85	2.56	18.42	96.83
1970		6.29	56.19		1.97	58.16	2.92	67.37	2.62	14.64	84.63
1971		4.33	50.36		1.98	52.34	2.92	59.59	3.02	12.01	74.62
1972		5.82	38.95		2.07	41.02	3.01	49.85	3.50	15.16	68.51
1973		4.83	35.79		3.04	38.83	3.01	46.87	5.61	19.75	72.03
1974		7.44	46.69		3.71	50.40	3.01	60.85	5.19	33.40	99.44
1975		10.88	28.90	0.18	3.41	33.39	3.01	47.28	1.93	32.75	31.96
1976		13.58	51.18	37.10	4.42	92.70	3.09	109.37	7.36	26.48	143.71
1977		11.46	30.22	146.36	2.15	178.73	5.12	195.31	7.15	26.74	229.90
1978		11.46	23.26	68.94	2.68	94.88	5.12	111.46	9.81	34.41	155.68
1979		12.40	110.46	62.10	3.67	176.23	5.12	193.75	12.26	41.68	247.69
1980		12.40	110.46	84.36	4.92	199.74	5.12	217.26	15.32	47.05	279.63
1981		12.40	-	58.56	5.99	64.55	5.12	82.07	19.16	46.38	147.61
1982		12.40	-	4.38	6.39	10.77	5.12	28.29	23.95	45.30	97.54
1983		12.40	-	4.96	6.39	11.35	5.12	28.87	29.94	46.64	105.45
1984		12.40	-	4.28	6.39	10.67	5.12	28.19	37.43	47.79	113.41
1985		12.40	-	4.78	6.39	11.17	5.12	28.69	49.79	46.88	122.36
After 1985		12.40	-	-	6.39	6.39	5.12	23.91	46.79	45.55	116.25
Total 1964-1985	463.67	558.05	828.21	467.21	260.66	1,564.86	330.72	2,917.31	1,651.62	1,978.59	6,547.52

Table 12

Summary of the benefits of the Nam Pong river development project
(from Sangsriratanakul, 1981)

Year	Power M฿	Irrigation M฿	Flood control M฿	Fishery M฿	Recreation M฿	Total Project benefit M฿
1966	31.41	-	11.0	2.41	0.60	45.62
1967	38.33	-	11.1	3.88	1.21	54.52
1968	36.08	-	10.6	6.12	1.05	53.85
1969	34.30	2.99	11.1	12.90	0.90	62.24
1970	35.84	3.30	10.7	10.04	1.21	61.09
1971	45.58	3.29	10.4	16.79	1.47	77.53
1972	40.43	3.06	11.6	14.42	1.60	71.11
1973	29.68	20.59	14.3	18.79	1.54	84.90
1974	40.95	29.95	18.1	27.45	1.28	117.78
1975	40.32	38.46	20.2	18.15	1.10	118.23
1976	62.18	29.61	21.0	38.0	1.66	152.47
1977	55.20	0.94	21.8	38.0	1.68	112.62
1978	56.08	12.28	22.7	38.0	1.68	130.74
1979	59.43	38.24	23.6	38.0	1.68	160.95
1980	60.40	68.87	24.6	38.0	1.68	193.55
1981	61.39	106.76	25.5	38.0	1.68	233.35
1982	62.41	147.70	26.6	38.0	1.68	276.39
1983	63.17	154.13	27.6	38.0	1.68	284.38
1984	64.55	155.96	28.7	38.0	1.68	286.69
1985	65.65	155.96	29.9	38.0	1.68	291.19
After 1985	65.65	155.96	31.1	38.0	1.68	292.39
Total benefit 1966 - 2016	2,955.73	5,650.89	1,314.10	1,650.95	79.71	11,643.63

Table 13

Estimated benefit cost ratio of the project (with total costs)
(from Sangsriratanakul, 1981)

Consecutive Year	Year	Annual cost M฿	Annual benefit M฿	Interest rate 6 per cent			Interest rate 8 per cent			Interest rate 10 per cent		
				Present worth factor	Present worth Value Cost M฿	Present worth Value Benefit M฿	Present worth factor	Present worth Value Cost M฿	Present worth Value Benefit M฿	Present worth factor	Present worth Value Cost M฿	Present worth Value Benefit M฿
-	1964	29.72	-	1.124	33.40	-	1.166	34.65	-	1.210	35.96	-
-	1965	65.38	-	1.060	69.30	-	1.080	70.61	-	1.100	71.91	-
0	1966	581.32	45.62	1.000	581.32	45.62	1.000	581.32	45.62	1.000	581.32	45.62
1	1967	73.00	54.52	0.934	68.86	51.43	0.9259	67.59	50.48	0.9091	66.36	49.56
2	1968	89.60	53.85	0.8900	79.74	47.92	0.8573	76.81	46.16	0.8264	74.04	44.50
3	1969	96.83	62.24	0.8396	81.29	52.25	0.7958	76.86	49.40	0.7513	72.74	46.76
4	1970	84.63	61.09	0.7921	67.04	48.38	0.7350	12.20	44.90	0.6830	57.80	41.72
5	1971	74.62	77.53	0.7473	55.76	57.93	0.6806	50.78	52.76	0.6209	46.33	48.14
6	1972	68.51	71.11	0.7050	48.29	50.13	0.6320	43.17	44.81	0.5645	38.67	40.18
7	1973	72.03	84.90	0.6651	47.91	56.46	0.5835	42.02	49.53	0.5132	36.96	43.57
8	1974	99.44	117.73	0.6274	62.38	73.86	0.5403	53.72	63.60	0.4665	46.38	54.92
9	1975	81.96	118.23	0.5919	48.51	69.98	0.5002	40.99	59.13	0.4241	34.71	50.14
10	1976	143.71	152.47	0.5584	80.24	85.13	0.4632	66.56	70.62	0.3055	55.40	58.78
11	1977	229.90	112.62	0.5268	121.11	59.32	0.4289	98.60	48.30	0.3505	80.57	39.47
12	1978	155.68	130.74	0.4970	77.37	64.97	0.3971	61.82	51.91	0.3168	49.63	41.42
13	1979	247.69	160.95	0.4688	116.12	75.45	0.3677	91.07	59.18	0.2897	71.75	48.36
14	1980	279.63	193.55	0.4423	123.68	85.60	0.3405	95.21	65.90	0.2663	73.62	51.54
15	1981	147.61	233.35	0.4173	61.59	97.37	0.3152	46.52	73.55	0.2394	35.33	55.86
16	1982	97.54	276.39	0.3936	38.39	108.78	0.2919	28.47	80.67	0.2176	21.22	60.14
17	1983	105.45	284.88	0.3714	39.16	105.80	0.2703	28.50	77.00	0.1978	20.85	56.35
18	1984	113.41	288.89	0.3503	39.73	101.19	0.2502	28.37	72.28	0.7199	20.40	51.97
19	1985	122.36	291.19	0.3305	40.43	96.23	0.2317	28.35	64.46	0.1635	20.00	47.61
20 - 50	1986-2016	116.25	292.39	4.2919	498.93	1,254.90	2.4148	280.72	706.06	1.4008	162.84	409.58
	Total	6,547.52	11,643.53	-	2,480.55	2,688.70	-	2,054.91	1,879.32	-	1,774.83	1,379.97

than from farming. The survey in 1978 showed that there were over 5,600 fishermen operating on this reservoir. The average annual fish catch was estimated to be 1,800 metric tons.

Besides the capture fisheries in the Ubolratana reservoir, fish farming was also introduced into the project area. At present, there are 183 fish ponds with a total surface area of 31 ha and 96 paddy fields covering a surface area of 65 ha which are used for fish culture in the Nong Wai irrigation area.

Gill-net is the most popular fishing gear in the Ubolratana reservoir. Capital investment in fishing is low, less than 1,000 baht per year. Fishermen usually sell their fish to fishmongers who buy fish in villages and/or on fishing grounds. Fishmongers then transport the fish to landing centres and sell them to wholesalers. From there, the wholesalers transport the fish to retail markets which are situated mainly in Khon Kaen and Udon Thani provinces. The average annual income of a fisherman is estimated to be 5,000 baht per person.

The total cost of the Nam Pong river development project is estimated at 6,547.52 million baht and the overall project benefit estimate is 11,643.53 million baht. When based on the project life of 50 years, the benefit-cost ratio is estimated 1.08, 0.91 and 0.77 for interest rates of 6, 8 and 10% respectively. The project appears therefore to be uneconomic.

9. REFERENCES

Bhukaswan, T. and S. Pholprasith, 1977 The fisheries of Ubolratana reservoir in the first ten years of impoundment. Proc.IPFC., 17(3):195-205

Jaiyen, K. et al., 1979 Plankton. In Nam Pong Environmental Management Project Working Document Number, 13. Bangkok, Mekong Secretariat.

Jindarojana, J. et al., 1979 Water quality. Nam Pong Management Research Project Working Document Number, 11. Bangkok, Mekong Secretariat.

Mekong Secretariat, 1972 Socio-economic aspects of fishery operations in the Nam Pong Reservoir 1970-1971. Bangkok, UN/ECAFE

Nookour, A. and O. Pawapootanon, 1983 Fish population investigation in Ubolratana Reservoir. Annu.Rep.Ubolratana Reservoir Fish Res.Stn., (1981-1982):48-56 (in Thai)

Parkla, S. and A. Deerat, 1977 Fisheries operations in Ubolratana Reservoir in 1977. Annu.Rep.Ubolratana Reservoir Fish.Res.Stn., (1977):77-85 (in Thai)

Sangsriratanakul, O., 1981 Evaluation and reappraisal of cost-benefit analysis for dam and reservoir projects in Thailand. Master's Thesis, Mahidol University, Bangkok, Thailand

Sethaputra, S. et al., 1979 Hydrological studies. In Nam Pong Environmental Management Research Project Working Document Number, 10. Bangkok, Mekong Secretariat

Sidthimunka, A. et al., Fisheries surveys in Ubolratana Reservoir between
1968 1965-66. Tech.Pap.Inland Fish.Div.Dep.Fish.,Bangkok (6) (in Thai)

Srisuwantach, V., Hydrobiological studies of Ubolratana Reservoir. Annu.
1970 Rep.Fish.Biol.Surv.Unit, (1970):174-90 (in Thai)

Suetrong, S. et al., Socio-economic studies. In Nam Pong Environmental
1979 Management Research Project Working Document Number, 8. Bangkok, Mekong Secretariat

Ubolratana Reservoir Fisheries Research Station, Fish landing statistics
1984 at the Ubolratana Reservoir, Khon Kaen province during 1969-1983. Rep.Ubolratana Reservoir Fish.Res.Stn., (1)

Varikul, V. et al., Water weeds and studies on fish, fish production and
1980 productivity. In Nam Pong Environmental Management Research Project Working Document Number, 12. Bangkok, Mekong Secretariat

Wacharakitti, S. et al., Land use. In Nam Pong Environmental Management
1979 Research Project Working Document Number, 3. Bangkok, Mekong Secretariat

Watanadilokgul, K. and C. Sribanjaem, Aquatic vegetation in Ubolratana
1982 Reservoir. Annu.Rep.Ubolratana Reservoir Fish.Res.Stn., (1981-1982):24-32 (in Thai)

APPENDIX A

Pre- and post-impoundment species composition of freshwater fish found in the Ubolratana Reservoir, Kohn Kaen, Thailand, during the period 1965 to 1982
(pre-impoundment - 1965; post-impoundment - 1966 to 1973, 1981, 1982)
(collected by rotenone treatment)

	Scientific names	1965	1966	1967	1969	1970	1971	1973	1981	1982
1.	Corica goniognathus (Bleeker)	+	–	–	+	+	+	+	+	+
2.	Notopterus notopterus (Pallas)	+	+	+	+	+	+	+	+	+
3.	Macrognathus aculeatus (Bloch)	+	+	+	+	+	+	+	+	+
4.	Mastacembelus armatus favus Hora	–	–	–	+	+	+	+	+	+
5.	M. armatus armatus Gunther	+	+	+	+	–	–	–	+	+
6.	M. circumcinctus Hora	–	–	+	+	+	+	+	–	+
7.	Fluta alba (Zuiew)	–	+	+	+	+	+	+	–	–
8.	Oxygaster oxygastroides (Bleeker)	+	–	–	+	–	–	–	–	–
9.	O. maculicauda (H.M. Smith)	–	+	+	–	–	–	–	–	–
10.	O. siamensis (Gunther)	–	+	+	+	–	–	+	–	–
11.	Paralaubuca riveroi (Fowler)	+	–	–	+	–	–	–	+	+
12.	Cultrops siamensis (Hora)	+	+	+	–	–	–	–	–	–
13.	Esomus metallicus Ahl.	+	+	+	+	+	+	+	–	–
14.	Luciosoma bleekeri Steindachner	+	–	–	–	–	–	–	+	–
15.	Rasbora heteromorpha Duncker	+	+	+	–	–	–	–	–	–
16.	R. borapetensis H.M. Smith	–	+	+	+	+	+	+	+	+
17.	R. argyrotaenia (Bleeker)	+	+	+	+	+	+	+	–	–
18.	R. trilineata Steindachner	+	+	+	+	+	+	+	–	–
19.	R. retrodorsalis H.M. Smith	–	+	+	+	–	–	+	–	–
20.	Mystacoleucus chilopterus (Fowler)	–	–	–	+	+	–	–	+	+
21.	Hampala macrolepidota van Hasselt	+	+	+	+	+	+	+	+	+
22.	H. dispar H.M. Smith	+	+	+	+	+	+	+	+	+
23.	Cyclocheilichthys apogon (Cuv. & Val.)	+	+	+	+	+	+	+	+	+
24.	C. enoplos (Bleeker)	+	+	+	+	–	–	–	–	–
25.	C. armatus (Cuv. & Val.)	–	+	+	–	–	–	–	+	+
26.	C. repasson (Bleeker)	+	+	+	+	+	+	+	–	–
27.	Barilius guttatus (Day)	+	–	–	–	–	–	–	–	–
28.	Cirrhinus jullieni Sauvage	+	–	–	+	+	+	+	+	+

Appendix A (Contd.)

	Scientific names	1965	1966	1967	1969	1970	1971	1973	1981	1982
29.	Puntius leiacanthus (Bleeker)	+	+	+	+	+	+	+	+	+
30.	P. sophoroides (Gunther)	+	−	−	+	−	−	+	−	−
31.	P. partipentazona (Fowler)	+	+	+	+	+	+	+	−	−
32.	P. gonionotus (Bleeker)	+	+	+	+	−	+	+	+	+
33.	P. viehoeveri Fowler	−	−	−	+	+	+	+	−	−
34.	P. orphoides (Cuv. & Val.)	+	+	+	+	+	+	+	+	+
35.	Puntioplites proctozysron (Bleeker)	+	−	−	+	+	+	+	+	+
36.	Osteochilus melanopleura (Bleeker)	+	−	−	+	+	+	+	+	+
37.	O. duostigma Fowler	−	−	−	+	+	+	+	−	−
38.	O. hasselti (Cuv. & Val.)	+	+	+	+	+	+	+	+	+
39.	O. vittatus (Cuv. & Val.)	+	+	+	−	−	−	−	−	−
40.	O. proaemion Fowler	+	−	−	+	−	+	+	−	−
41.	O. spilopleura Fowler	−	+	+	−	−	−	−	−	−
42.	Labiobarbus burmanicus (Day)	−	−	+	+	−	−	−	−	−
43.	L. spilopleura (H.M. Smith)	+	+	+	−	−	−	+	−	−
44.	L. lineatus (Sauvage)	−	−	−	+	+	+	+	+	+
45.	L. kuhlii (Cuv. & Val.)	−	−	−	+	+	+	+	−	−
46.	Morulius chrysophekadion (Bleeker)	+	−	+	+	+	+	+	+	+
47.	Labeo bicolor H.M. Smith	+	−	+	−	−	−	−	−	−
48.	L. erythrurus Fowler	+	+	+	+	−	−	−	+	−
49.	Lobocheilus quadrilineatus (Fowler)	−	+	+	+	+	+	+	−	−
50.	L. nigrovittatus H.M. Smith	−	−	−	+	+	+	+	−	−
51.	Crossocheilus reba (Hamilton)	+	−	−	−	−	−	−	−	−
52.	Mekongina erythrospila Fowler	+	−	−	−	−	−	−	−	−
53.	Botia hymenophysa (Bleeker)	+	−	−	−	+	+	+	−	+
54.	B. horae H.M. Smith	+	+	+	−	+	+	+	+	+
55.	B. modesta (Bleeker)	+	+	+	−	−	−	−	+	+
56.	B. beauforti H.M. Smith	+	−	−	−	−	−	−	−	−
57.	Epalzeorhynchos coatesi (Fowler)	−	−	−	+	−	+	−	−	−
58.	Acanthophthalmus javanicus (Bleeker)	+	+	+	+	+	+	+	−	−
59.	Acanthopsis choirorhynchos (Bleeker)	+	+	+	+	+	+	+	−	−

Appendix A (Contd.)

	Scientific names	1965	1966	1967	1969	1970	1971	1973	1981	1982
60.	Lepidocephalus octocirrhus (van Hasselt)	+	−	+	+	+	+	+	−	−
61.	Cobitophis anguillaris (Vaillant)	+	+	+	+	+	+	+	−	+
62.	Noemacheilus poculi H.M. Smith	+	+	+	−	−	−	−	−	−
63.	Wallagonia attu (Bloch)	+	−	+	+	+	+	+	−	−
64.	Ompok bimaculatus (Bloch)	+	+	+	+	+	+	+	−	+
65.	Kryptopterus cryptopterus (Bleeker)	+	−	−	+	−	−	−	−	−
66.	K. apogon (Bleeker)	+	−	−	+	−	+	+	+	−
67.	K. bleekeri Gunther	+	−	−	−	−	−	−	−	−
68.	Clarias batrachus (Linn.)	+	+	+	+	+	+	+	+	+
69.	C. macrocephalus Gunther	−	−	+	+	−	+	+	−	−
70.	Pteropangasius cultratus (H.M. Smith)	+	−	−	−	−	−	−	−	−
71.	Leiocassis siamensis Regan	+	−	−	+	−	+	+	+	−
72.	L. albicollaris Fowler	−	−	−	+	−	−	−	−	−
73.	Mystus vittatus (Bloch)	+	+	+	+	+	+	+	−	−
74.	M. atrifasciatus Fowler	−	−	−	+	+	+	+	−	−
75.	M. nemurus (Cuv. & Val.)	+	+	+	+	+	+	+	+	+
76.	M. wyckii (Bleeker)	+	−	−	−	−	−	−	+	+
77.	M. gulio (Hamilton)	+	+	+	−	−	−	−	−	−
78.	M. cavasius (Hamilton)	+	+	+	+	+	+	+	−	−
79.	Heterobagrus bocourti (Blaekar)	−	−	−	+	−	+	−	−	−
80.	Bagarius bagarius (Hamilton)	+	−	−	−	−	−	−	−	−
81.	Xenentodon cancila (Hamilton)	+	+	+	+	+	+	+	+	+
82.	Synaptura aenea H.M. Smith	+	−	−	−	−	−	−	−	−
83.	Anabas testudineus (Bloch)	+	+	+	+	+	+	+	−	−
84.	Trichopsis vittatus (Cuv. & Val.)	+	+	+	+	+	+	+	−	−
85.	T. schallerii (Ladiges)	−	−	−	−	+	+	−	−	−
86.	Betta splandens Regan	+	−	−	+	+	+	+	−	−
87.	Trichogaster microlepis (Gunthar)	+	−	+	−	−	−	−	−	−
88.	T. trichopterus (Pallas)	+	+	+	+	+	+	+	+	+
89.	T. pectoralis (Regan)	+	−	+	+	+	+	+	+	+

Appendix A (Contd.)

	Scientific names	1965	1966	1967	1969	1970	1971	1973	1981	1982
90.	Channa striatas Bloch	+	+	+	+	+	+	+	+	+
91.	C. gachua Hamilton	+	+	+	+	+	+	+	-	-
92.	C. lucius (Cuv. & Val.)	+	-	+	+	+	+	+	-	-
93.	C. micropeltes (Cuv. & Val.)	+	+	+	+	+	+	+	-	[illegible]
94.	Chanda wolffii (Bleeker)	+	+	+	-	-	-	-	-	-
95.	C. siamensis Fowler	-	-	+	+	+	+	+	+	+
96.	Pristolepis fasciatus (Bleeker)	+	+	+	+	+	+	+	+	+
97.	Nandus nandus (Hamilton)	+	+	+	-	-	-	+	-	-
98.	N. nebulosus (Gray)	+	-	-	+	+	+	+	-	-
99.	Oxyeleotris marmoratus (Bleeker)	+	+	-	+	+	-	+	+	+
100.	Tetraodon leiurus Bleeker	+	-	-	+	+	-	+	+	+
101.	Probarbus jullieni Sauvage	-	-	-	-	-	+	+	-	-
102.	Cirrhinus molitorella (Cuv. & Val.)	-	-	-	-	-	+	-	-	-
103.	Ctenopharyngodon idella (Cuv. & Val.)	-	-	-	-	-	+	+	-	+
104.	Aristichthys nobilis (Richardson)	-	-	-	-	-	-	-	-	+
105.	Pangasius sutchi Fowler	-	-	-	-	-	-	-	-	-
106.	Datnoides microlepis Bleeker	-	-	-	-	-	-	-	-	-
107.	Hypophthalmichthys molitrix (Cuv. & Val.)	-	-	-	-	+	+	-	-	+
108.	Notopterus chitala (Hamilton)	-	-	-	-	-	+	-	-	+
109.	Labeo rohita (Hamilton)	-	-	-	-	-	-	-	-	-
110.	Pangasius snitvongsei H.M. Smith	-	-	-	-	-	-	-	-	-
	Total species found	76	52	62	78	58	67	68	37	37

Remarks: + = present species
- = absent species

C. THE MAHAWELI BASIN (SRI LANKA)

by

Sena S. De Silva
Department of Zoology
University of Ruhuna
Matara
Sri Lanka

ABSTRACT

The River (= Ganga) Mahaweli is the largest river in Sri Lanka and its basin covers approximately one-sixth of the island. The Mahaweli Ganga development was initiated in 1970 according to the Master Plan (1965-1969) of the United Nations Development Programme and the Food and Agriculture Organization, with a view to bringing about an increased area of the dry zone of the country under cultivation, to provide through the year irrigation facilities for existing land and to meet the increasing demand for hydroelectric power. In 1977 the plan was reviewed and in the light of the increasing cost of food imports and unemployment the Mahaweli Ganga Diversion and Development Programme was telescoped into a six-year period.

Although the Mahaweli basin accounts for 15-20% of the inland fish production in Sri Lanka, during the planning and execution of the project, particularly during the construction of the reservoirs, the development of the fisheries sector was not taken into consideration. This contribution discusses the effects of the Mahaweli Ganga development on the existing reservoir fishery and suggests ways for optimizing the fishery in reservoirs, villus (= flood lakes) and irrigation channels.

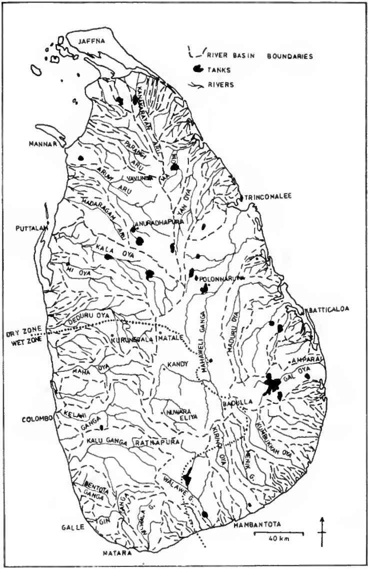


Figure 1. Major rivers and their basins in Sri Lanka.

1. INTRODUCTION

Sri Lanka is an island (6°-10°N; 80°-82°E) of approximately 63,000 km^2, which is thought to have separated from the Indian mainland in the Miocene. A stretch of sea 32 km wide separates the two land masses now. The island has a coastline of 1,760 km and a continental shelf area of nearly 31,000 km^2 (De Silva and De Silva, in press). Nearly nine-tenths of the island's bedrock beneath the superficial deposits is composed of Pre-cambrian crystalline rocks, some of which are over 2 billion years old; over the rest of the area, chiefly along the north-west coastal belt sedimentry rocks of the Upper Gondwana (Jurassic) and Miocene age form the underlying bedrock (Cooray, 1967).

Topographically, Sri Lanka may be divided into three peneplains, the first from 0-122 m, the second rising as a steep step with elevations from 364-762 m and the third rising as a further steep step from the second and having an elevation of 1,530-1,828 m. These peneplains are believed to be important with respect to the floral and fauna distribution on the island (Senanayake and Moyle, 1981).

Climatically, the island is characterized by the effects of the two monsoons - the Southwest and the Northeast and their corresponding intermonsoonal periods. Typically, the Southwest prevails from about May to September and the Northeast from October to March. On the basis of the rainfall pattern the island is divided broadly into two distinct zones, the wet and the dry zones, each covering approximately 25% and 75% of the island respectively. The dry zone receives on average below 1,900 mm of rainfall per annum and has only one rainy season from about October to March. More detailed classification based on the rainfall pattern has also been attempted (Domros, 1976). The mean annual precipitation in the dry zone is estimated to be around 70 x 109 m^3 and that in the wet zone 39 x 109 m^3 (Arumugam, 1969).

Historically, the major civilizations were almost always concentrated in the dry zone of the country. However, with the advent of foreign rule since 1505 and the consequent conquering of the whole island by the British, the settlement pattern and the agricultural traditions began to change. During foreign rule, emphasis began to be laid on cash crops, initially coffee and thereafter on tea, rubber and coconut, which are all wet zone crops. During the course of this century the population of Sri Lanka doubled from 6 million to 12 million in a span of 40 years (1931 to 1971), and now stands at 15.5 million. At the existing rate of growth of 1.8 the population of the island is projected (medium projection) to reach 22.7 million at the turn of the century, resulting in a mean density of 358 persons/km^2 (Jones and Selvaratnam, 1972).

The increase in the population has had obvious and glaring influences directly on the natural resources of the island as well as indirectly through the increased demand on amenities such as electricity, etc. The forest cover on the island has declined to 44.5% of the land area and the area under mono-cultural practices over the period 1871-1972 has increased from 435,000 ha to 1,710,000 ha, i.e. from 6.7% of the total land area to 26.4% (Domros, 1976).

Since independence in 1948, all governments have given top priority to food production, with the aim of being self-sufficient in rice, subsidiary crops, fish, sugar, etc. Consequently, apart from technological advances that have been achieved in bringing about an increased production, mostly through application of fertilizers, proper irrigation, selective breeding, etc., the area under cultivation of major crops has also been increasing, e.g. the area under rice-paddy increased from 370,000 ha to 586,000 ha during the period 1946 to 1972 (Domros, 1976).

Bringing an increased area under the plough has necessitated the provision of proper irrigational facilities. This has been achieved in two ways: restoring a number of ancient irrigation works (Brohier, 1934, 1935) since the second quarter of this century, and venturing on a number of new river basin development schemes since 1948. River basin development is not something alien to the people of Sri Lanka. The hydrological engineering feats of the ancient times remain a part and parcel of the life of the rural masses of Sri Lanka. The greatest era in the history of modern civilization of the island was during the reign of Parakrama Bahu I (1153-1186). It is recorded in the Mahavansa the Great chronicle of Sri Lanka (Geiger, 1960, in Arumugam 1969) that he was responsible for the construction, restoration and enlargement of 163 major reservoirs, 2,376 minor reservoirs, 165 anicuts and 3,910 channels from reservoirs and anicuts; the achievements of a ruler who believed that not even a drop of rain water should go to the sea, without benefitting man. The building of large reservoirs by damming of rivers and large streams resulted in the invention of a sophisticated sluice for the control of the outflow and the original valve-pit designed by the ancient Sinhala engineers for this purpose has remained almost unchanged (Brohier, 1934, 1935; Schnitter, 1967).

The backbone of the existing irrigational facilities constitutes over 10,000 man-made lakes (Fernando, 1971) with an estimated water surface area of 130,000 ha (Fernando and De Silva, 1984; Mendis, 1977) or approximately 2.1 ha of water surface for every km^2 of Sri Lanka.

The increasing demand for agricultural produce and hydropower for the projected increase in the population, cannot be satisfactorily met with the existing irrigational and hydroelectric facilities. It is in this context that further major development of a river basin - the Mahaweli - has been planned and undertaken since 1970.

2. RIVERS - GENERAL CONSIDERATIONS

Sri Lanka has 103 perennial rivers, locally known as either Ganga, Aru, or Oya. Of these, only 23 river basins are larger than 500 km^2 and 80 of them are located in the dry zone of the country (Fig. 1), covering approximately 73.2% of the island. Of the dry zone basins, the Mahaweli accounts for nearly 23%.

2.1 Run-off

The total river run-off from the dry zone and wet zone basins is 25.5x10.9x10.9 m^3 and 25.8x109 m^3 respectively. The run-off during the two main seasons for those individual basins over 500 km^2 and the others, grouped together, for the two zones is given in Table 1. The run-off from the rivers vary widely due to the pattern of rainfall, type of soil, slope, etc. Generally, rivers in the dry zone have a poor run-off, varying from 10% to 50% of the total precipitation. The annual run-off in the two climatic zones in relation to the precipitation is given in Table 2.

2.2 Floodplains

In any sort of river basin development the nature of the floodplain needs to be considered in detail. The floodplains are important from the point of view of fish production and form an important habitat, mostly temporary, for breeding populations of certain species, as well as nursery grounds and/or feeding grounds for others (Welcomme, 1979).

Table 1

River basin area, river discharge during the yala[1] and maha[1] seasons from the 23 major rivers and that of the other minor rivers (modified after Arumugam, 1969; 1 - refers to cultivating seasons which are based on the rainfall pattern)

River	Basin km^2	Run-off in 10^6 m^3 Maha	Yala	Total
Dry Zone				
Walawe Ganga	2,442.2	1,389.5	812.0	2,201.5
Kirindi Oya	1,164.8	540.5	122.2	662.7
Kumbukkan Oya	1,218.6	636.7	86.4	723.1
Heda Oya	604.2	336.9	35.8	372.7
Gal Oya	1,792.0	1,632.6	117.2	1,749.8
Mundeni Aru	1,280.0	713.3	38.3	751.6
Maduru Oya	1,541.1	1,310.5	87.6	1,398.1
Mahaweli Ganga	10,327.0	3,499.6	1,814.0	5,313.6 1/
Yan Oya	1,520.6	754.0	30.9	784.9
Ma Oya	1,024.0	459.0	14.8	473.8
Kanakanayan Aru	896.0	401.1	14.8	415.9
Aruvi Aru	3,246.1	1,187.1	51.8	1,238.9
Moderagama Aru	931.8	230.0	11.1	241.1
Kala Oya	2,772.5	981.0	79.0	1,060.0
Mi Oya	1,515,5	134.5	14.8	149.3
Deduru Oya	2,616.3	1,194.5	313.4	1,507.9
Others	11,591.8	5,939.2	441.8	6,381.0
Sub Total	46,484.5	21,340.0	4,085.9	25,425.9
Wet Zone				
Kelani Ganga	2,265.6	2,927.0	4,238.8	7,165.8
Kalu Ganga	2,688.0	3,456.4	4,310.4	7,766.8
Bentara Ganga	622.1	818.1	942.8	1,760.9
Gin Ganga	921.6	905.8	1,006.9	1,912.7
Nilwala Ganga	960.0	771.3	721.9	1,493.2
Maha Oya	1,510.4	981.0	956.4	1,937.4
Attanagalu Oya	727.0	372.0	392.4	764.4
Others	2,369.3	1,632.6	139.8	1,772.4
Sub Total	12,064	11,864.2	12,709.4	24,573.6
Grand Total	58,548.5	33,204.2	16,795.3	49,999.5

1/ Elsewhere in the text, the discharge, based on 1950-1977 records, is given as 8.3 $10^9 m^3$, of which 5.8 $10^9 m^3$ is to be utilized. (Ed.note)

Table 2

Precipitation and run-off (in 10^9 m^3)

	Dry Zone	Wet Zone	Total
Annual precipitation	70.3	39.5	109.8
Run-off	25.5	25.9	51.3
	(37.5%)	(65.0%)	(47%)
Balance	44.8	13.6	58.5
	(62.5%)	(35.0%)	(53.0%)

The total floodplain area, inclusive of those lakes which will retain water through the year (locally known as villus) is estimated to be around 41,050 ha (Mendis, 1977), which is small in comparison to the extent of the river basins on the island. Perhaps, this limitation is brought about by the short length of rivers from the point of origin to the discharge into the sea and the steep gradient of the river beds.

2.3 Riverine ichthyofauna

Sri Lanka's geological history has resulted in an ichthyological diversity lower than would be expected for a tropical island very close to the mainland (Fernando, 1971). According to Darlington (1957) mountain stream fish did not reach the Indian mainland until the Pliocene and did not therefore reach Sri Lanka which separated from its mainland in the Miocene period. Nevertheless, some of these species, as well as secondary freshwater species were able to migrate from the Indian mainland across 'bridges' formed during depressions of sea level during the ice ages.

Fifty-one species of teleost fishes indigenous to the island have been recorded (De Silva et al., 1981). Of these species 42 are believed to be typically riverine and the rest to be marsh-dwelling (Fernando and Indrasena, 1969; De Silva, in press). There is uncertainty regarding the number of species endemic to Sri Lanka; according to Evans (1981) there are 17 constituting 33% of the indigenous fauna, whereas according to De Silva (in press) there are only 14 species which are taxonomically accepted.

Senanayake and Moyle (1981) recognised three ichthyological provinces based on the distribution of the indigenous fauna; the Southwestern Province - the richest, containing 15 endemic species of which 12 are restricted to the province, the Mahaweli Province with 4 endemic species (two confined to the province) and the dry zone province (Fig. 2). These provinces have a superficial relationship to the three peneplains of the island. The ichthyorichness of the Southwestern Province was attributed to high and more constant rainfall, the higher forest cover and the greater diversity of the available habitats.

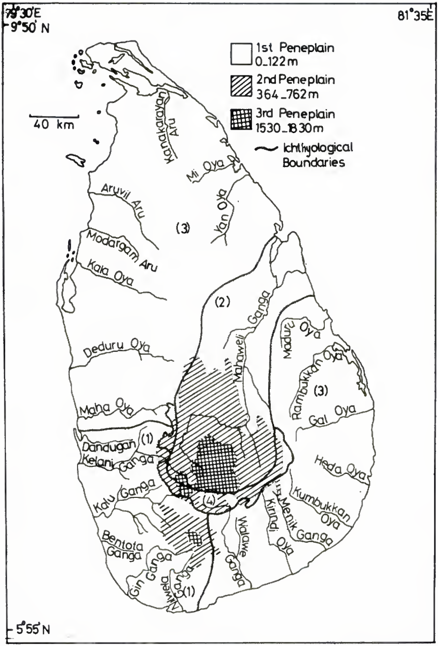


Figure 2. Ichthyological provinces in relation to the three peneplains of the island (from Senanayake and Moyle, 1981).

2.4 Fish introductions

Since the first recorded introduction of Salmo trutta in 1882,eighteen species of food fishes have been introduced into the freshwaters of Sri Lanka (Table 3). Apart from these three transplantations, one typically estuarine and two catadromous species have been made. The role of exotics in the inland fishery of Sri Lanka has been aptly documented (Fernando, 1971; De Silva, in press). Of the introductions the cichlid, Oreochromis mossambicus (Peters) has not only been the most successful, but also has been singled out as the species which was indirectly involved in the establishment of a viable reservoir fishery on the island.

There are no records to show that the Indian and Chinese major carps have bred naturally, although they have been successfully bred in hatcheries (Weerakoon, 1979). A similar success has been achieved with Cyprinus carpio. As such, the role of these species in the fishery of Sri Lanka lies in their utilization, either in extensive and/or intensive cultural practices.

Of the transplanted species Etroplus suratensis has established itself in rivers (Willey, 1910) as well as in reservoirs (De Silva et al., in press), and contributes in varying extents to individual reservoir fisheries.

2.5 River basin development

Apart from the ancient development of some river basins, in the course of this century the following major river basins have been developed or are in the process of being developed, either solely, for irrigational purposes or for irrigation and hydroelectric power generation:

(a) Gal Oya Basin;
(b) Walawe Ganga Basin;
(c) Mahaweli Ganga Basin;
(d) Kirindi Oya Basin;
(e) Kala Oya Basin.

Among these, the Mahaweli Ganga basin development is the largest from the point of view of capital works, area irrigated, hydropower and environmental manipulation. It is also associated and interconnected with the development of the Kala Oya and Maduru Oya basins. In the following chapters the Mahaweli Ganga basin and its development are considered in detail.

3. MAHAWELI GANGA (= RIVER)

The Mahaweli river is the largest and the longest river in Sri Lanka. It originates in the Adam's Peak range near Hatton, at an elevation of about 2,000 m. The Mahaweli Ganga which is 332 km long, flows north and then northeast and drains into the sea at Trincomalee Bay, the deepest and the largest bay of Sri Lanka (Fig.3). The main river runs through six of the twenty-five administrative districts of Sri Lanka.

The headwaters of the Mahaweli originate on the Hatton plateau, into which enter seven subsidiary rivers, viz. Kurundu Oya, Belihul Oya, Maha Oya, Kotmale Oya and Nan Oya from the south, and Ma Oya and Hulu Ganga from the north. The upper catchment of the Mahaweli covers about 316,000 ha. In the lower basin there are three major tributaries that enter the

Table 3

Fish introductions into Sri Lanka with comments on their reproductive biology
(updated from Fernando, (1971) * re-introductions; ** transplantations)

Species	Origin	Date	Stocking	Breeding	Remarks
Salmo trutta	Europe	1882-1893	Hill streams	+ (Fernando, 1971)	Stocks supplemented from the hatchery annually
Salmo gairdneri	N. America	1889-1893	Hill streams	+ (Fernando, 1971)	Stocks supplemented from the hatchery annually
Cyprinus carpio (2 strains)	Europe	1915	Streams/reservoirs	+ (Fernando, 1971)	Breeding not confirmed
Carassius carassius	Europe	1915	Streams/reservoirs	+ (Fernando, 1971)	
Osphronemus goramy	Indonesia	1909	Streams/reservoirs	+ (Fernando, 1971; Ellepola & Fernando, 1968)	No longer important as a food fish
Ctenopharyngodon idella	China	1948/1973*	Reservoirs		Bred in fisheries station, Udawalawe (Weerakoon, 1979)
Hypophthalmichthys molitrix	China	1973			Bred in fisheries station, Udawalawe (Weerakoon, 1979)
Aristichthys nobilis	China	1978			
Catla catla	India	1942/1981*			Reared in experimental stations
Labeo rohita	India	1982			Reared in experimental stations
Trichogaster pectoralis	Malaysia	1951	Lagoons/marshes	+ (Fernando, 1971; Indrasena, 1965)	
Oreochromis mossambicus	E. Africa	1952	Reservoirs	+ (Fernando and Indrasena, 1969)	Very important in reservoir fisheries
O. niloticus		1956/1975[a]	Reservoirs	+ (personal observation)	Food fish common in certain reservoirs
Tilapia rendalli	E. Africa	1969	Reservoirs	+ (Chandrasoma and De Silva, 1981)	Food fish
O. hornorum[b]	E. Africa	1969	Experimental (?)		(no data available on the present status of these introductions nor have any of the species been reported in the catches
T. zilli[b]	E. Africa	1969	Experimental (?)		
Helostoma temmencki	Thailand	1951			
Puntius gonionotus[c]	S.E. Asia				
Etroplus suratensis	Lagoons	1910	Reservoirs/rivers	+ (Willey, 1910)	Important catch in certain reservoirs
Chanos chanos**d	Lagoons				
Mugil cephalus **d	Lagoons				

a - Mendis (1977); b - no records of these introductions are available; c - Jhingran and Gopalakrishnan (1974);
d - no organized transplantation carried out

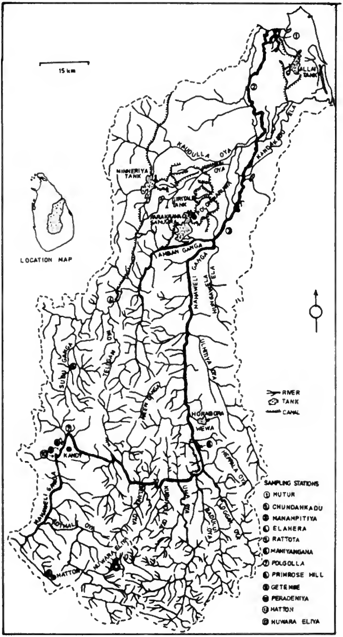


Figure 3. The Mahaweli Ganga and its tributaries.

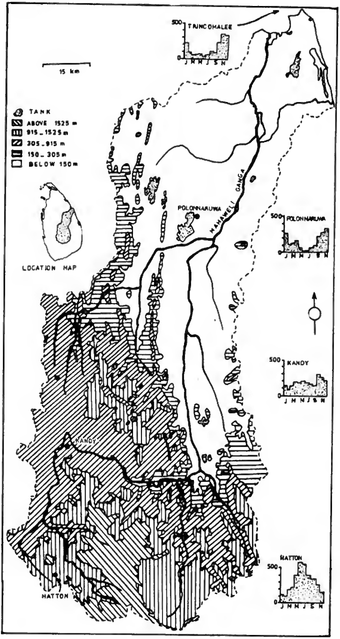


Figure 4. The topography of the Mahaweli Ganga Basin. Also indicated is the mean annual precipitation for different parts of the basin (modified from Hunting Survey Corporation, 1962).

Mahaweli: Amban Ganga, Ulhitiya Oya and Kaudulla Oya. The Mahaweli River Basin covers 10,420 km^2 - about one-sixth of the island area. The topographic features of the basin are shown in Figure 4, and the distribution of land area according to elevation is given in Table 4. The 150 m contour closely coincides with the edge of the lowland plain and the area enclosed by this contour constitutes nearly half of the basin.

Table 4

Distribution of land area according to elevation in the Mahaweli Basin

Elevation Zone	Area (km^2)	% of Basin area
0 - 150	4,740	45.5
150 - 350	982	9.4
350 - 650	1,502	14.5
650 - 1,300	2,108	20.2
1,300 - 2,000	847	8.1
over 2,000	241	2.3
Total	10,420	100.0

3.1 Climate

The climate of the Mahaweli Basin is largely influenced by monsoons, with the single most important climatic parameter being the rainfall. The annual temperature variations are small, although there are significant differences between the up-stream and the down-stream areas.

3.1.1 Rainfall

The mean annual rainfall ranges from 1,650 mm in the downstream area to 5,300 mm in the upper-catchment (Fig. 4). The pattern is largely physiographically controlled. The highest parts of the hill country, which are exposed to the full force of the monsoons, experience the greatest rainfall, while the lowland plains and the 'rain shadow areas' in the hill country receive a much lower rainfall. The upper catchment receives the greatest rainfall during the southwest monsoon from May to September, and the northeast monsoon from December to January produces the least rainfall, February usually being the driest month of the year. The lower basin, on the other hand, receives the most amount of rainfall during the northeast monsoon (November/December to February/March) with adequate rainfall during October and November - the intermonsoonal rains of convectional and cyclonic origin. The two cultivation periods known as Maha and Yala correspond to the two monsoonal periods of northeast and southwest respectively.

The effective precipitation for the basin was found to range from 12 mm in September to 114 mm in November (UNDP/FAO, 1969). The annual total effective precipitation was 681 mm.

The island is divided into a dry and a wet zone by climatologists using the 75 inch average isohyet. Drawing of this single boundary, however, fails to emphasize the existence of a transition zone - the intermediate zone. The Mahaweli Basin contains large areas of wet, dry and intermediate zones. Hunting Survey Corporation (1962) reconstructed the zone boundaries taking into consideration annual rainfall, seasonal rainfall distribution, physiography, soils and the distribution of agricultural land uses and forest types (Fig.5). They also divided the Mahaweli Basin into rainfall regimes taking into consideration the monthly rainfall regardless of the totals involved.

On this basis three regimes were recognised:

(a) Regimes dominated by the southwest monsoon rainfall (SW>IM>NE) - only one area of the Mahaweli Basin belongs to this regime.

(b) Regimes dominated by northeast monsoon rainfall (NE>IM>SW) - the largest area of the Mahaweli Basin falls into this regime and is represented in all three zones.

(c) Regimes dominated by rainfall of the intermonsoonal periods (IM>SW>NE, IM>NE>SW>IM>NE>SW) - these regimes predominate in five areas of the basin.

3.1.2 Floods

The occurrence of floods in the lower Mahaweli Ganga is mainly confined to the periods of the northeast monsoons and the months immediately preceeding it. The major floods are mostly associated with tropical revolving storms or cyclones that are common during that period (Thambayahpillay, 1959). Because of the steep slopes and intense rainfall in the upper catchment area flood flows in Mahaweli Ganga are typically quick rising and also tend to regress rapidly (Fig.6).

3.2 Soils

Fifteen great soil groups have been identified in Sri Lanka (UNDP/FAO, 1969), of which the following six are reported to occur in the Mahaweli Basin: the reddish brown earth (RBE); the non-calcic brown (NCB); The low humic gley (LHG); the recent alluvials (RAL); the old alluvials (OAL); and the solodized solonetz (SS) soils.

In the lower basin area thirty-five major and minor soil series, representative within the above six great soil groups have been established (TAMS, 1980). Details of drainage and soil permeability classes, depth of the bedrock, water holding capacity, soil colour and electrical properties are known for all the minor soil groups (TAMS, 1980). The distribution of soil types in the Mahaweli Basin in relation to some other river basins are also dealt with by Moorman and Panabokke (1961) and Panabokke (1967).

3.3 Surface Water

3.3.1 Stream Flow

From the gauging records (1950-1977) at Manampitiya (Fig.3), it has been estimated that the mean annual flow of the Mahaweli Ganga is approximately 8.3 billion m^3. The upper basin of the Mahaweli receives appreciable amount of rain throughout the year (Fig.5) while the lower basin receives most of its rainfall during the northeast monsoon. As such, the seasonal range of streamflow is not as large as that of the rainfall in the lowland area; for example, at Manampitiya the average

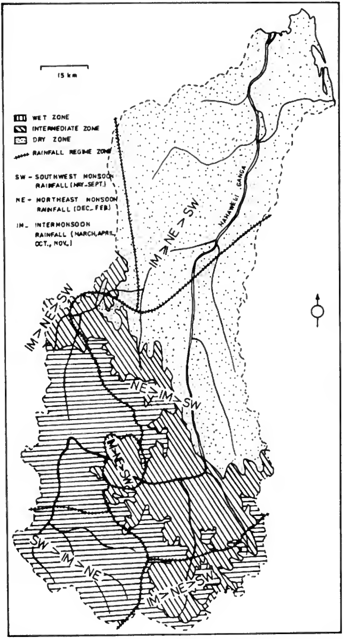


Figure 5. Rainfall pattern on the Mahaweli Basin (from Hunting Survey Corporation, 1962).

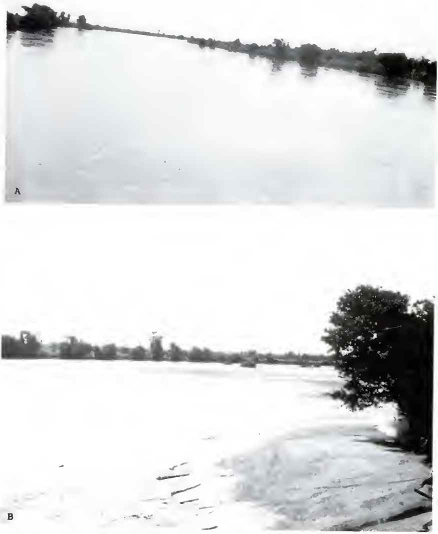


Figure 6. The Mahaweli Ganga - a river of extremes.
A. The Ganga at full spate, December 1983 as seen from the Manampitiya Bridge to the north.
B. The Ganga at its lowest, February 1983.

flow during one dry season (March to September) is approximately 46% of that of the wet season, although the rainfall in the dry season is only 27% of that in the wet season.

The mean monthly flow at Manampitiya for the 1950-1977 period and that for 1955/56 which is considered as a critical year is shown in Figure 7. The mean monthly flows at four other selected sites are given in Table 5 (after NEDECO, 1979).

3.3.2 Water quality

The water quality parameters of surface waters of the Mahaweli river and its tributaries have been measured since 1960 (Table 6). For convenience and clarity those data collected within a 5 km range have been pooled. In the main river the dissolved solids content, electrical conductivity, concentration of ions increase downstream. The same parameters have lower values in tributaries in the hilly country as compared to those in the plains.

DDT has been in use in Sri Lanka for nearly 30 years, initially sprayed to control mosquito vectors of malaria parasities and later as a pesticide in paddy and other cultivations. Apart from DDT other organochlorine compounds such as heptachlor, endrin, aldrin, and dieldrin have been extensively used (Weeraratne, 1983). Organochlorine pesticides degrade extremely slowly, and tend to accumulate along the food chain. The residual levels of chlorinated pesticides were measured in surface waters of the Mahaweli Ganga, floodplain lakes, and major reservoirs (Table 7, from TAMS, 1980).

For the reservoirs and villus, the best water quality data are available for the reservoir Parakrama Samudra (Gunatilaka and Senaratne, 1981; Gunatilaka, 1983). The main physico-chemical data for the perennial as well as some seasonal or village tanks are summarized in Table 8. The analysis of the limnological information for the Parakrama Samudra suggests that the productivity of the lake is somewhat nutrient limited (Schiemer and Duncan, 1983). The phosphorus content showed strong diurnal dynamics, being limiting during the day (Gunatilaka, 1983). In addition, the high flushing rates also affect nutrient dynamics and productivity patterns. The Parakrama Samudra has a flushing rate that is nearly double that of Minneriya and Kaudulla (Table 12) and as such the influences of the flushing rate on the nutrient and phyto- and zooplankton dynamics of the latter reservoirs are likely to be far greater.

Table 5

Mean monthly flows of Mahaweli Ganga at selected, important sites
in million cubic meters (after NEDECO, 1979)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Polgolla	116	70	64	107	199	299	273	249	239	321	284	218	2,438
Minipe	408	264	172	247	334	415	400	368	349	501	528	538	4,524
Manampitiya	1,203	709	422	471	508	502	478	448	435	694	966	1,459	8,289
Elahera	151	93	55	49	46	27	25	22	21	57	104	178	829

Table 6

Water quality of the Mahaweli and its tributaries. The mean and the range for each parameter is given when available (modified after TAMS, 1980). The locations are given in Fig. 3.

Location	Year	pH	Hardness	EC	TDS	meq l^{-1}					
			meq l^{-1}	us	mg l^{-1}	Ca	Mg	Na	K	HCO_3	Cl
Mahaweli	60,61	7.2	19.6	48.9	43	0.25		0.11	0.06	0.51	0.25
Polgolla/Peradeniya/ Getambe/Primrose Hills	79	(6.2[c]-7.7[a])	(12-33)[e]	(20[c]-115[e])	(24-74)[e]	(0.15-0.34)[a]		(0.08-0.14)[a]	(0.02-0.13)[a]	(0.02-0.80)[c]	(0.11-0.39)[c]
Victoria Dam Site	79[c]	6.8	-	60		0.35	0.13	0.12	-	0.61	-
Mohiyangama	79[g]	7.0	-	95		0.53	0.22	0.15	-	1.15	-
Manampitiya	79	6.8[d]-8.0[g]	-	90		0.53[d]-0.85[g]	0.16[d]-22[g]	0.21[g]	-	0.94[g]-1.29[d]	0.28[d]
Muttur, Chundankadu	79[g]	7.0	-	132-2120		0.66 -1.23	0.34	0.22-13.2	-	1.35 -1.81	-
Amban Ganga	60,61	7.4	-	169	107	0.52[g]	0.24[g]	0.20	0.05	0.98[g]	-
Elahera	79	(5.0-8.1)[a]	-	(75-270)[a]	(60-146)[a]			(0.14[g]-0.31[a])	(0.03-0.09)[a]		
Rattota	72,79	6.5[f]-7.0[c]	15[c]	83	-	-	-	-	-	-	0.14[c]
Kotmale Oya											
Dam Site	63,77,78	7.0	10.5	33	22	0.23	0.06	-	-	0.21	0.20
	79	(6.4-7.2)[d]	(9-14)[d]	(19-50)[d]	(13-35)[d]	(0.10-0.46)[d]	(0.04-0.08)[d]			(0.16-0.30)[g]	(0.17-0.28)[d]
Talawakelle	79	7.0[c,g]	10[c]	22.5	-	-	-	-	-	-	0.14[c]

a to g - Sources; a - U.S. Operation Mission (1961); b - Pattiarachchi & De Silva (1972); Ceylon Association of Science Presidential Address;
d - Government Analyst Department Records; e - National Water Supply and Drainage Board Records; f - Dr. G. Schut (field notes);
g - TAMS data

Table 7

Chlorinated pesticide residues in selected surface waters of the Mahaweli Ganga and associated reservoirs and villus in microgram per litre (TAMS, 1980)

Location	Aldrin	Dieldrin	Benzene-hexachloride	Endosulfan	Total DDT
Mahaweli Ganga					
Victoria Dam Site	0.01	0.06	0.17	-	0.05
Manampitiya	0.01	-	0.13	-	0.07
Mutur	0.07	-	0.22	-	0.41
Kotmale Dam Site	0.02	0.04	0.21	0.06	0.47
Flood Lakes					
Karapola Villu	0.07	0.06	0.19	0.10	0.38
Velankada Villu	0.01	0.14	0.20	0.04	0.27
Reservoirs					
Parakrama Samudra	0.04	-	0.22	-	0.13
Minneriya	0.04	0.03	0.17	-	0.25
Kaudulla	0.02	-	0.18	-	0.12

Seasonal reservoirs (village tanks), in comparison to the larger reservoirs, have a higher availability of nutrients as well as a higher potential production (Mendis, 1965; Oglesby, 1979, 1980).

3.4 Ground water

The availability of ground water depends on the amount of surface flow that percolates into the sub-soil, which in turn is dependent on the nature of sub-soil and the amount of rainfall. Very little information is available on the ground-water resources in Sri Lanka. In the dry zone the amount of rainfall available for infiltration into the sub-soil is limited due to low rainfall.

The major ground water resources of the Mahaweli Basin occur in the miocene limestone belt (Fig.8) in the north-western, northern and north-eastern part of the basin. The annual recharge to ground water in this area is estimated at 150-250 mm per annum (Fernando, 1973). In this region the bed rock is covered by red alluvial soils which have a very high infiltration rate, and water is trapped in the solution cavities and in canal systems along joints and fractures (NEDECO, 1979).

3.5 Land use

The pattern of land use of the upper catchment of the Mahaweli Basin differs significantly from that of the downstream area. The overall land use pattern of the Mahaweli Basin is summarised in Table 9 and Figúre 9.

The upper catchment has four major land use groups:

(a) the intensively managed lands, comprising 49% of the watershed area, of which two-thirds are under tea;

(b) 14% under dry land agriculture;

Table 8

Some water quality data for the major reservoirs and seasonal tanks of the Mahaweli Ganga basin

	Area	Mean depth at full supply level	pH	Conductivity (microsiemens)	Alkalinity mq/l	Plankton mg m^3
Major Reservoirs						
Parakrama Samudra	2,662	5.3	7.0–8.9[a]	184[a]	1.7[a]	–
Minneriya	2,550	5.3	7.0–7.5[b]	221[b]/193[c]	1.4[c]	6.9[d]
Kaudulla	2,537	5.1	7.5–8.0[b]	252[b]/380[c]	1.8[b]	–
Giritale	356	8.6	7.5–8.0[c]	140–168[c]	4.1[c]	8.4[d]
Seasonal Tanks (Data extracted from Thayaparan, 1982, unless otherwise stated)						
Kolkanaweliwewa	18.0	–	6	59	–	21
Dalukan Wewa	68.0[d]	–	7	161	–	6
Thimbirigaswewa	5.7	–	–	365	2.4	–
Kudahatawewa	6.5	–	–	–	2.7	–
Aralaganwila	158.0[d]	–	–	–	2.5	–
Moragaswewa	12.0	–	–	92	1.0	–
Floodplain Lakes						
Gengala V.	256	–	6.7[e]	175[e]	–	–
Karapola V.	600	–	6.7[e]	260[e]	High HCO_3-	
Mutugalla V.	420	–	6.8[e]	875[e]	High Saline	

a – Gunatilaka and Senaratne, 1981; b – Oglesby, 1979; c – De Silva (unpublished)

d – Mendis, 1977; e – TAMS, 1980.

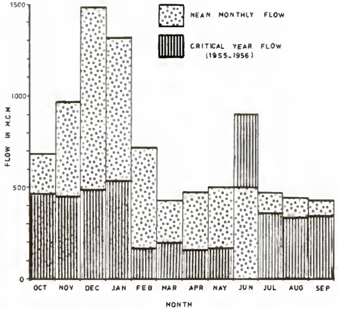


Figure 7. Mean monthly flow of the Mahaweli Ganga at Manampitiya (1950-1977) as compared with that for the critical year 1955/56 (from NEDECO, 1979).

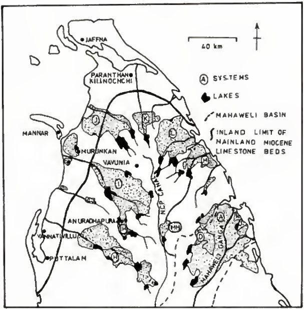


Figure 8. Ground water resources of the Mahaweli basin (from NEDECO, 1979).

Table 9

Mahaweli Ganga Basin - summary of land use
(modified from Hunting Survey Corporation, 1962)

Land Use	Wet Zone		Intermediate Zone		Dry Zone		Total	
	ha	%	ha	%	ha	%	ha	%
Urban	1 650	0.6	500	0.2	306	0.2	3 060	0.3
Homestead Garden	32 490	10.8	22 390	10.0	15 280	2.9	70 150	6.7
Rubber	9 460	3.2	3 695	1.7	-	-	13 160	1.3
Tea	133 920	44.7	11 490	5.1	-	-	145 415	13.9
Paddy	21 902	7.3	21 731	9.7	28 490	5.4	72 126	6.9
Other permanent cultivation	7 270	2.4	11 860	5.3	15 203	2.9	34 330	3.3
Shifting cultivation	7 270	2.4	87 380	39.0	58 690	10.3	148 250	14.2
Grassland and Scrub	27 646	9.2	18 540	8.3	27 290	5.2	73 480	7.0
Forest	56 170	18.8	45 345	20.2	358 320	68.5	459 800	43.9
Unused land	573	0.2	370	0.2	5 370	1.0	6 313	0.6
Water and Marsh	1 126	0.4	760	0.3	18 620	3.6	20 508	1.9

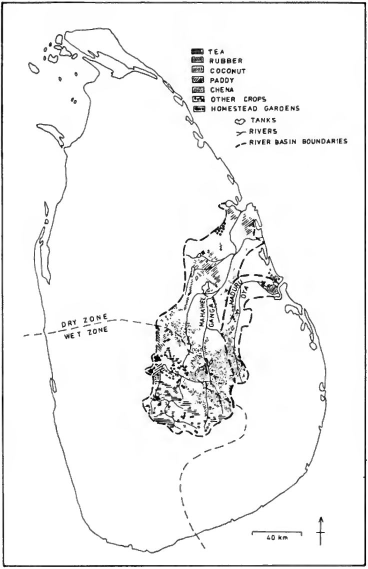


Figure 9. Major patterns of land use in the Mahaweli Basin (from Ceylon 1969).

(c) 14% under forest, and

(d) 22% is misused land which is either in the form of scrub, chena (= small crop cultivation) grassland or abandoned tea (TAMS, 1980).

The upper catchment is characterized by steep slopes, with nearly 75% of the land having slopes of 21% to 40%. Over the last 25 years the land area used for intensive agriculture has decreased from 87,000 to 63,000 hectares, and the forest cover by almost half.

The downstream area covers approximately 500,000 ha and the extent of usage for different purposes is given in Table 10.

Table 10

Present land use in the downstream area of the Mahaweli Basin (modified from TAMS, 1980)

Land use	Extent ha
Rice Land	75,000
Chena	90,800
Other cropland	48,000
Pastures, Grasslands, etc.	24,000
Forest, scrub and woodland	140,000
Surface water	10,000
Other land	3,000
Total	390,800

The lower basin has been one of the most intensively used land on the island, due to the ancient irrigation works resurrected and improved in the course of this century.

3.6 Settlement patterns

Population density changes from 1871 to 1978 in the different administrative districts which fall within the Mahaweli Basin are given in Table 11.

Over the 100-year period the population density in the lower basin has increased by nearly ten-fold as compared to the six-fold increase in the upper basin area. The present population density distribution in those districts which fall within the Mahaweli Basin is shown in Figure 10. Although the lower basin has experienced higher degree of change, its significantly lower population density and the consequent availability of a greater land area makes this portion of the basin more suitable for future development.

4. INLAND FISHERIES IN THE MAHAWELI BASIN

In Sri Lanka the inland fisheries are characterized by two major factors: firstly it is almost entirely confined to the man-made lacustrine water bodies that are perennial, and secondly an exotic species tilapia *Oreochromis mossambicus* forms the backbone of this fishery (Fernando and Indrasena, 1969; Fernando, 1971; De Silva, in press; Fernando and De Silva, 1984). The reasons for the success of this exotic, the present status of the fishery as a whole, and certain management strategies of the fishery have been documented (Wijeyaratne and Costa, 1981; De Silva, 1985). The fishery of the Mahaweli Basin is no exception to this general pattern. However, the Mahaweli Basin being the largest, and having the largest floodplain as well as a large surface area of reservoirs both ancient and recent, has a major role to play in the inland fisheries.

4.1 Riverine fishery

The Mahaweli Ganga, like the other rivers in Sri Lanka does not support a commercial fishery. A subsistence fishery using sporadic cast netting, hook and line is carried out throughout the river length. Willey (1910) documented the paucity of a riverine fishery on the island and briefly dealt with the methods of existing subsistence fishery, which varied from hook and line to poisoning using extracts of poisonous creepers. The most intensive fishing takes place in the estuary where it is limited mostly to shrimps. Apart from shrimps, milkfish (*Chanos chanos*) and grey mullet are captured by using castnets. The season of the shrimp fishery is between March and August. However, there are no statistics available.

4.2 Reservoirs

The distribution of reservoirs in the Mahaweli Basin is shown in Figure 11. The reservoirs in Sri Lanka are classified according to irrigation terminology into (i) the major irrigation reservoirs, (ii) the medium-scale irrigation reservoirs, (iii) the minor irrigation reservoirs, and (iv) the hill-country reservoirs.

Table 11

The trends of population change (persons per km^2) in the administrative districts falling within the Mahaweli Basin from 1871 to 1978 (data from Statistical Abstracts, 1979)

District	1871	1881	1891	1901	1911	1921	1931	1946	1953	1963	1971	1978
Nuwara Eliy	48	81	90	126	128	138	194	221	268	328	371	386
Kandy	99	127	123	161	175	186	251	304	359	446	508	549
Mutale	32	38	33	40	47	50	56	68	87	130	160	180
Polonnaruwa	06	06	07	08	09	09	09	14	22	34	49	56
Batticaloa	13	15	17	20	22	22	25	29	38	81	106	123
Trincomalee	07	08	10	11	11	13	14	28	31	54	73	86
Mean Density												
Upper Basin	60	82	82	109	117	125	167	198	205	301	346	372
Lower Basin	09	10	11	13	14	15	16	24	30	56	76	88

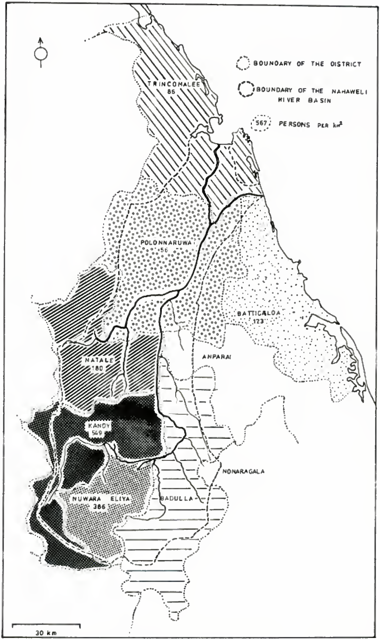


Figure 10. Population density in 1978 in administrative districts falling within the Mahaweli Basin.

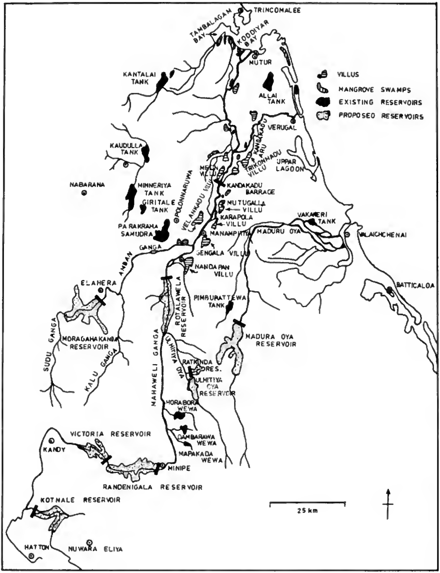


Figure 11. The major reservoirs, villus (= floodplain lakes) and mangrove swamps of the Mahaweli Basin (from Tams, 1980).

However, from the point of view of fisheries development, those in the Mahaweli Basin can be categorized into two types: (i) the perennial reservoirs, and (ii) the seasonal or village tanks. The latter tend to dry up almost completely for two to three months in the year, and generally are of a smaller size, often being less than 20 ha at the full supply level. These reservoirs are presently utilized only marginally for fish production, even though their potential use for fish production was highlighted by Mendis (1965). The major fishing activities of the Mahaweli Basin are confined to the major perennial reservoirs in the basin which approximate 10,000 ha of surface area.

4.2.1 The fishery

The total yield from the reservoir fishery of the basin presently stands at approximately 3,000 metric tons (1980 data) averaging a yield of 375 kg/ha/annum. Some morphometric, hydrological and physico-chemical features of relevance to fish production and the present status of the fisheries in the major reservoirs are summarized in Tables 12 and 13 respectively.

The fishery in all the reservoirs is dominated by the exotic species Oreochromis mossambicus (Peters). Fernando and Indrasena (1969) and De Silva and Fernando (1980) traced the history of the development of the fishery of the Parakrama Samudra reservoir and showed convincingly the importance of O. mossambicus to the fishery. Fernando and Indrasena (1969) and later Fernando (1971) suggested that the introduction of this species in 1952 has been instrumental in the establishment of the reservoir fishery in Sri Lanka (Fig.12). Mendis (1977) erroneously interpreted that Tilapia rendalli, introduced in 1962, dominated the fishery in this reservoir. There is increasing evidence that in almost all the reservoirs throughout the island, O. mossambicus accounts for more than 50% of the landings (De Silva, in press; Fernando, 1977).

4.2.2 Crafts, gear and efficiency

The reservoir fishery throughout the island remains somewhat uniform in that the type of crafts and the gear used remain the same. Two types of crafts were used until recently (Fig. 13), dug-out log canoe or a log-raft, both being manoeuvered by two persons. These are gradually being replaced by fibre glass canoes of similar design and size under a recently introduced subsidy scheme (Sri Lanka, 1980). The fibre-glass craft has not increased the fishing efficiency in comparison to the traditional dug-out canoe. The biggest advantage of the former is its longer lifespan.

The gear is exclusively a gill-net of mesh size ranging from 8-12 cm. Each craft carries on average four net lengths, each length of approximately 20 m. The nets are laid at dusk and hauled during the early hours of the morning. Beach seining is prohibited in the reservoirs of Sri Lanka and the topography of the bottom and the numerous obstructions, primarily trees, prevent the use of any bottom dragging gear. The uniformity of the crafts and the gear used permits the computation and the comparison of catch per unit effort data from different reservoir fisheries. In most of the reservoirs fishing effort has been on the increase over the last few years, and particularly so in those reservoirs which have already had established fisheries and which are located in the vicinity of townships. The best examples are the Parakrama Samudra and the Minneriya reservoirs of the Mahaweli Basin.

Table 12

Some morphometric, hydrological and physico-chemical fe4atures of the major reservoirs of the Mahaweli Basin (Where appropriate, the ranges are given: EC - electrical conductivity; Rt - retention time)

Reservoir	Area	Mean depth	Annual^a		Rt^a	pH	EC	Alkalinity
			Inflow	Outflow				
		m	mcm		yr			meql^{-1}
Parakrama Samudra	2 662	3.8	149	151	0.38	8.0^e (7.04 - 8.9)	184^e (161 - 255)	1.7^a (1.22 - 3.34)
Minneriya	2 551	4.8	541	541	0.15	8.1 (7.7^c - 8.6^b)	190 (155^b - 221^c)	2.7 (4.1^b - 1.4^c)
Kaudulla	2 470	2.2	178	179	0.15	7.9 (7.6 - 8.2)^b	279 (200 - 380)^b	2.6 (1.8^c - 3.4^b)
Kantalai*	1 912	3.7	178	179	0.28	7.2^d	-	-

a - NEDECO (1979); b - Personal observations (1980-1983); c - Oglesby (1981); d - Mendis (1965); e - Gunatilaka and Senaratne (1981); * - Kantalai reservoir is located at the edge of the northern limit of the Basin

Table 13

Fisheries in three major reservoirs and one medium-scale reservoir in the Mahaweli Basin

Reservoir	Years	No. of Crafts	Yield Total (t)	kg/ha/yr	No. of Crafts	*O. mossambicus* %
Parakrama Samudra	73 - 82	73	911	342	12 471	68.8
Minneriya	76 - 82	62	510	200	5 087	67.0
Kaudulla	79 - 82	67	501	198	7 991	62.0
Giritale*	80 - 82	65	31	101	3 631	63.5
Pimburettewa*	80 - 82	65	589	710	9 061	59.8

* medium-scale reservoirs; Giritale - in the Mahaweli Basin and Pimburettewa in the Maduru Oya Basin

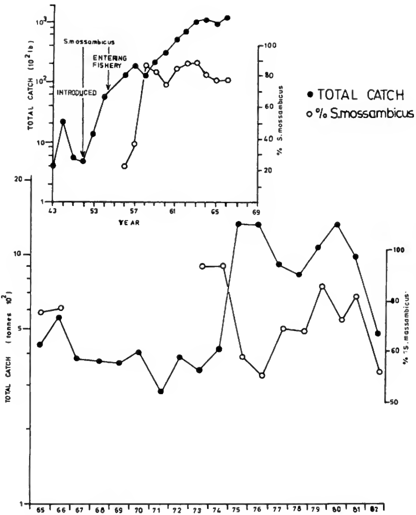


Figure 12. Total catch from Parakrama Samudra (Fernando and De Silva, 1984).

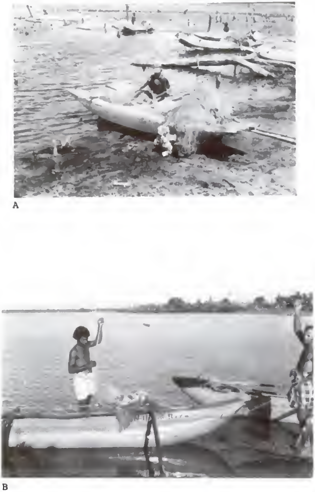


Figure 13. The crafts: the old type (A) and the new (B). Note the bundle of netting - gillnet of 8-12 cm stretched-mesh.

The changes in the effort, measured as the number of craft-days/ha/ year over the period for which reliable data are available for the Parakrama Samudra and Minneriya fishery are shown in Figure 14. The data available show that while the effort has been steadily rising (in the case of Parakrama Samudra since 1976 and in both reservoirs since 1980), in both reservoirs yield/craft/year showed a significant decline since 1980. The present yield per craft is 3.7 metric tons (mt) and 4.5 mt in Parakrama Samudra and Minneriya respectively - a yield which is barely profitable to the fisherman.

4.2.3 Seasonal changes

Sesonal changes in the total yield of the two major fisheries of the Mahaweli Basin reservoirs are shown in Figure 15. The seasonal changes in the total yields as well as the yield per unit of effort follow a similar trend in that the yield increases during the rainy periods, the highest yield being in September to December in both reservoirs. The biological significance of this phenomenon has been dealt earlier by De Silva (1983).

4.2.4 Species composition

As stated earlier, the reservoir fishery in Sri Lanka is dominated by the exotic cichlid, Oreochromis mossambicus (Peters), introduced in 1952 (Fernando and Indrasena, 1969; Fernando, 1977). The same holds true for the reservoirs of the Mahaweli Basin (De Silva and Fernando, 1980). Fernando and Indrasena (1969) listed the fish species that are found in Parakrama Samudra reservoir and this was recently updated by Schiemer (1983) (Table 14).

Apart from O. mossambicus only two other species (Labeo dussumieri and Puntius sarana) contribute significantly to the commercial catches, at any time of the year. In addition to these three species, others such as Wallago, Channa sp. etc., also occur in the catches in small numbers, and are important constituents because they command a relatively high price.

The percentage contribution of the two important indigenous species viz. Puntius sarana and Labeo dussumieri to the total yield is shown in Figure 16. Since 1976 there has been a decrease in catches of the indigenous species, and there are also seasonal changes (Fig. 17) with a significant increase during the rainy season (De Silva, 1983).

4.2.5 Recent trends

The data available on the mean landing size of O. mossambicus from the Parakrama Samudra fishery over the years indicate a gradual decrease in the mean landing size (Table 15). The decrease in the mean landing size was interpreted as an indication of stunting of the population (TAMS, 1980). TAMS (1980) however, failed to recognize the possible effects of increased fishing pressure on the mean landing size as well as the changes in the gear utilized in the early phases of the fishery.

More recently in all the major reservoirs of the Mahaweli Basin the half beak, Hyporamphus gaimardi has begun to appear. In the Kaudulla and Minneriya reservoirs, as well as in certain reservoirs of the Walawe Ganga basin a small fishery has developed for this species. The present estimated yield from Kaudulla reservoir approximates 20 kg/ha/year.

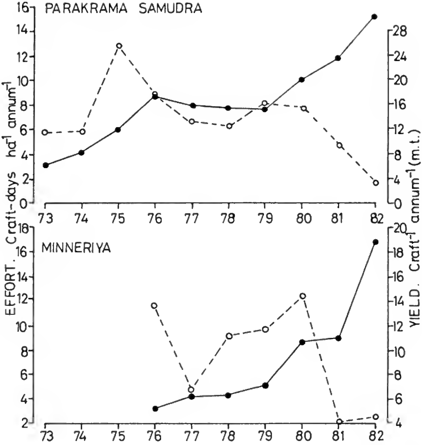


Figure 14. Fishing effort and yield per unit effort in the Parakrama Samudra and Minneriya reservoir fisheries.
- ● Effort
- o Yield per craft

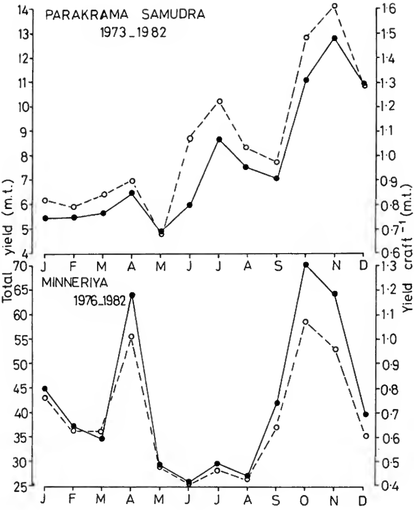


Figure 15. Seasonal changes in the Parakrama Samudra and Minneriya reservoir fisheries.

● Yield

o Yield per crft

Table 14

Fish species recorded from Parakrama Samudra and other reservoirs of the Mahaweli Basin, with notes on their feeding and breeding habits (modified from Fernando and Indrasena, 1969)

Family/Species	Food	Breeding
ANGUILLIFORMES		
Anguilla bicolor bicolor	C	
A. nebulosa nebulosa	C	
BELONIFORMES		
Hyporamphus gaimardi	Z/O[b]	
CLUPEIFORMES		
Ehirava fluviatilis	Z (Schiemer and Duncan, 1983)	
CYPRINIFORMES		
Amblypharyngodon melettinus	H (Schiemer and Hofer, 1983)	
Danio aequipinnatus	O	
Esomus danrica thermoicos	O	
Heteropneustes fossilis	H	
Labeo dussumieri	H	(De Silva, 1983)
Mystus keletius	O[b]	
M. vittatus	O[b]	
Ompok bimaculatus	C	
Puntius chola	O	(De Silva, 1983)
P. dorsalis	H/O	(De Silva, 1983)
P. filamentosus	H/O	(De Silva, 1983)
P. sarana	H/O	(De Silva, 1983)
P. vittatus[b]	O	
P. ticto[b]	O	+[b]
Rasbora daniconius	O	
MASTACEMBELIFORMES		
Mastacembelus armatus		
OPHIOCEPHALIFORMES		
Channa striatus	C	
PERCIFORMES		
Etroplus maculatus		
E. suratensis	O[a]/H (De Silva et al. in press)	+[b]
Oreochromis mossambicus	O[a]	+[b]
Tilapia rendalli	H[b]	+[b]
Glossogobius giuris	C	+[b]

a - data from Schiemer, 1983; b - personal observations; breeding - within reservoirs or not; O - omnivore; H - herbivore; C - carnivore; Z - zooplanktivore

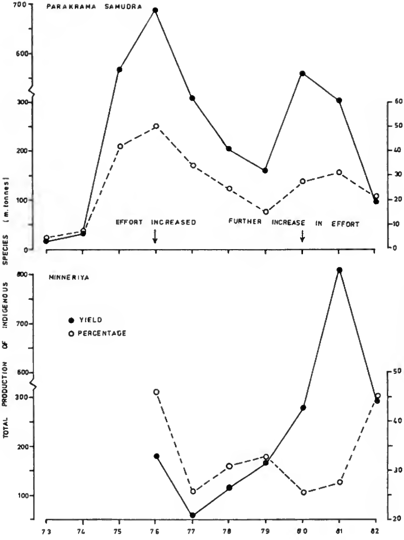


Figure 16. Yield of indigenous species and their percentage contribution to the total yield in the Parakrama Samudra and Minneriya reservoir fisheries.

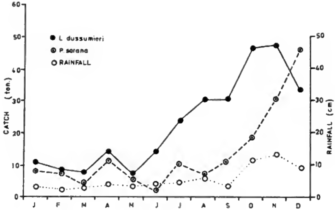


Figure 17. Seasonal changes in the yield of Labeo dussumieri and Puntius sarana (Parakrama Samudra and Minneriya reservoir fisheries) (from De Silva, 1983).

Table 15

Changes in the mean size of landing of *O. mossambicus* in the Parakrama Samudra fishery

Year	Mean Size Length (cm)	Weight (g)	Source
1957	34.2	-	Fernando (1971)
1957	34.2	659	Anonymous (1960)
1964	28.4	338	Fernando (1977)
1966	27.2	343	Fernando (1967)
1978	21.8	191	De Silva and Fernando (1980)
1982/83	23.5	230	De Silva (1984)
For the 1982/83 period the mean landing size for 3 other reservoirs			
Minneriya	23.3	215	De Silva (1984)
Kaudulla	21.6	151	
Giritale	23.8	244	

4.2.6 Untapped resources

The existing fisheries of the major reservoirs remain uniform in the gear and the crafts utilized. Catches are dominated by the exotic *O. mossambicus* , which is supplemented mostly by two indigenous species. As such, the smaller indigenous species, in particular the long snouted barb - *Puntius dorsalis*, the filamented barb - *Puntius filamentosus*, the green barb - *Puntius chola*, giant danio - *Danio aequipinnatus*, the attentive carp - *Amblypharyngodon melettinus*, the indigenous carnivores such as snake heads - *ophiocephalids*, cat fishes and eels remain underexploited or unexploited. Preliminary results of experimental fishing in Parakrama Samudra (Schiemer and Hofer, 1983) have indicated considerable resources of minor cyprinids. In a few reservoirs elsewhere on the island, notably in Mahawillachchiya and Nachchaduwa, a fishery for *D. aequipinnatus* and *P. filamentosus* exists in addition to the *O. mossambicus* fishery.

The occurrence of carnivores in present catches is accidental and negligible. It is suggested that initial surveys for long-lining and use of small-meshed gill-nets should be carried out to ascertain the extent of these resources. Based on such evaluations, management measures could be introduced to effectively tap these resources without harming the existing fishery. A tentative estimate based on the very preliminary fishing activities suggests that a minor carp yield of 20-50 kg/ha/year and a carnivore yield of 10-25 kg/ha/year could be obtained in addition to the existing yield from the major fishery.

4.2.7 Biological considerations

The reservoir capture fisheries on the major reservoirs depends almost entirely on natural recruitment. Apart from the lacustrine species, which are exotic, the reservoir fish populations contain a number of indigenous riverine as well as marsh-dwelling species, some of which presently contribute significantly to the constituent fishery. Evidence has been brought forward to show that the commercially important indigenous species do not breed in the reservoirs, and that they undertake a spawning migration, which is also indirectly responsible for the higher yields during the rainy period (De Silva, 1983). Apart from these species the same appears to be true for some other indigenous minor cyprinids such as *Puntius dorsalis*, *P. filamentosus* and a few other species.

A gradual decrease from 34.2 cm in 1957 to 21.8 cm in 1980 in the mean landing size of *O. mossambicus* in the Parakrama Samudra reservoir has been interpreted as *an indication* of stunting (TAMS, 1980). However, this could also be the result of the increased fishing pressure which has taken place over the same period of time. The fishing pressure has increased almost ten fold and under such conditions even if the gear and the mesh size have not changed, a considerable decrease in the mean landing size is to be expected. The present mean landing size of *O. mossambicus* is comparable to that in fisheries on much larger water bodies elsewhere in Asia or Africa (e.g. Gwahaba, 1973; Welcomme, 1967), and fish of this size have a high market acceptability.

Since 1952, the major reservoirs of the Mahaweli Basin have been stocked with at least four exotics: *O. mossambicus*, *Tilapia rendalli* (= *melanopleura*), *Cyprinus carpio* and *O. niloticus* and to a lesser extent with *Ctenopharyngodon idella*. However, apart from *O. mossambicus* which dominates the fishery, ony *T. rendalli* occurs in the fishery to any extent. The biological reasons for the dominance of *O. mossambicus* and the lack of success of the other species remain obscure. Apart from the two cichlids there is no evidence of natural recruitment of the other introduced species.

4.2.8 Marketing

Marketing of the reservoir fish is very traditional. Each fisherman or groups of fishermen sell their catches to specific vendors, most of whom transport the fish on bicycles (Fig. 18). The traders arrive at the landing sites - which for a major reservoir vary from 4 to 6 - in the early hours of the morning, and buy the catch at a pre-fixed price. The price paid to the producer by the vendor is determined by the latter, and has not increased over the years in relation to the increase in the cost of living index.

The vendors trade in specific townships which they have allocated amongst themselves. Trading is mostly from house to house. The retail price of fish increases when outside labour is brought in for harvesting. In addition, the prices also tend to be determined by availability.

In most areas the selling price is determined by the size of fish, with a bigger fish fetching a higher price than a smaller one. Fish are rarely sold by weight.

During the peak fishing periods a significant proportion of the catch is salted and sun-dried. Sun-drying is particularly popular amongst the migrant fishermen who move into the reservoir from the coast during the monsoonal periods.

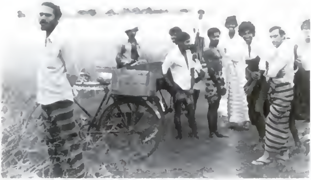
4.3 Flood lakes - Villus fishery

Sri Lanka is estimated to have only 40,000 ha of flood lakes (hereafter referred to as villus) of which 16,000 ha are reported to be in the Mahaweli Basin (Hunting Surveys, 1962). The more recent estimate (TAMS, 1980) of villu area is given as 12,800 ha, with 50 distinct villus. Of these the three largest villus (Fig.11) are Handapan Villu, Karapola Villu, and Velankadu Villu, which range in area from 400 to 900 ha.

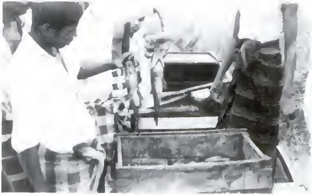
Villus are vegetated land areas saturated with water seasonally and retaining their connection to the main river most of the year. A villu generally consists of two portions; the ponding area which is permanently filled with water, and the floodplain which is inundated by water during the flood period.

Villus constitute a major habitat for a number of indigenous species of fish, amphibians and birds, and a grazing ground for livestock. The villus are also the breeding ground of some riverine fishes, such as the commercially important Labeo dussumieri (Dr. M. Smith, personal communication).

Fishery statistics are not available for most of the villus. Fernando (1977) gave a total mean yield of 84,490 kg (141 kg/ha/year) for the years 1964-67 for Karapola Villu, one of the largest villus of the Mahaweli Basin. It was also shown that O. mossambicus constituted 65% of the catch. More data are available since 1980 (Table 16), with a mean fish yield from the villus being 133 kg/ha/year. The available evidence suggests that the fish yield is, at least partially, determined by the existing fishing pressure and that in some of them the fishing pressure could be increased without harming the fish stock. The author has



A.



B

Figure 18. A - Vendors gathered at one of the landing sites.

B - A vendor selling his goods.

observed that the mean size of O. mossambicus landed was 18 cm (approx. 170 g), which is considerably smaller than that landed from reservoirs. Mahaseer (Tor khudree), each weighing 8-10 kg , were not uncommon in the villus. During the flood seasons an increased number of people take up to fishing with cast-nets, primarily in the littoral, and the main constituent species of the catch during this period are Labeo dussumieri and Puntius sarana (Dr. M. Smith, personal communication).

A fishery also exists for a shrimp (Macrobrachium sp.) in all the major villus. This fishery is seasonal, being confined to the dry months and is carried out by women wading into the littoral and seining through aquatic plants (Fig.19). The average catch per fisherman per day ranges from 6 to 8 kg (wet weight). In Karapola Villu, for example, about 20 women are engaged in this activity each day and the season lasts for about 12 weeks. The approximate shrimp yield from this villu per annum is computed as 12 mt/year.

4.4 Aquaculture

The aquaculture practices in the Mahaweli Basin which are still in their formative stages are both extensive, e.g. stocking and harvesting of village seasonal tanks, and entensive, e.g. pond and cage culture.

The Mahaweli Basin is estimated to have nearly 4,000 ha of seasonal tanks, most of which are less than 10 ha in surface area. Stocking and harvesting of four village tanks was undertaken during the 1981/82 growing period. These tanks were stocked with equal proportion of bighead carp, grass carp and O. niloticus fingerlings ranging from 2,500 to 3,500 fingerlings per ha. Only two of the tanks were harvested while the others dried up before the end of the growth period (Thayaparan, 1982).

Intensive aquaculture is still carried out only on an experimental scale. Sri Lanka has no aquaculture tradition in contrast to other countries of the region, perhaps primarily due to its strict Buddhist traditions. The current intensive aquaculture involves pond and cage culture. Preliminary results of these operations are discussed by Hettiarachchi (1982) and Wannigama and Weerakoon (1982).

Table 16

Fish yield from major villus in the Mahaweli Basin
(data furnished by Mr. A. Hetiarachchi, Ministry of Fisheries;
the number of boats operating are given in parentheses)

Villus	Area ha	Total Production tons			kg ha^{-1} $annum^{-1}$				tonnes $craft^{-1}$ $annum^{-1}$			
		80	81	82	80	81	82	Mean	80	81	82	Mean
Handapana V.	890	202 (22)	210 (80)	72 (13)	227	236	81	181	9.2	7.0	5.5	7.2
Gengala V.	256	51 (2)	14 (4)	13 (3)	199	55	51	102	25.5	3.5	4.3	11.1
Karapola V.	600	157 (33)	20 (8)	91 (44)	262	33	152	149	4.8	2.5	2.1	3.1
Mutugalla V.	420	41 (10)	12 (6)	31 (15)	98	29	74	67	4.1	2.0	2.1	2.7
Velankadu V.	768	111	191	81	145	249	105	166	6.5	4.8	2.4	4.6

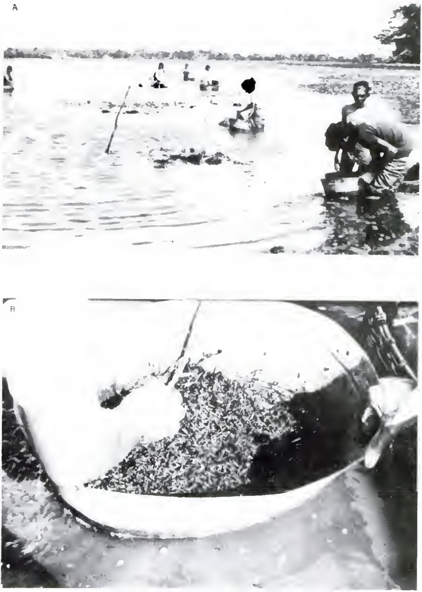


Figure 19. A - Women fishing for shrimp in the littoral area of the villu - Karapola villu, Manampitiya.

B - A catch of shrimp.

5. THE MAHAWELI GANGA DIVERSION AND DEVELOPMENT

The Mahaweli Ganga diversion and the associated river basin development remains the biggest project ever undertaken in Sri Lanka, in terms of the capital input, the extent of sociological, economical and ecological impact and in the time-scale for its completion. The present development scheme cannot, however, be divorced from the ancient works associated with the Mahaweli Ganga, and this is to be expected in the light of the irrigational supremacy that was prevalent in the Sri Lankan nation for over 2,000 years (Schnitter, 1967).

5.1 Historical aspects

"Let not even a drop of rain water go to the sea without benefitting man" (PARAKRAMA BAHU THE GREAT, 1153 - 1186 AD).

The old Sinhala civilizations were centered in the dry zone. The earliest kingdoms were based in Anuradhapura and Polonnaruwa in the heart of the dry zone. It was therefore, imperative for their survival that all efforts were made to maximize the utilization of the water that fell on the earth. It was due to the foresight of rulers such as King Parakrama Bahu, whose regime is recognized as one of the most important irrigational eras in the history of the island, that vast-scale irrigational works were created. There were several ancient major irrigation systems in the Mahaweli Basin (Fig.20). These went into disrepair over the years. Since the 19th century a number of channels have been reconstructed, such as the Elahera-Minneriya Yoda Ela, almost all the major tanks (reservoirs) reconstructed and rehabilitated and the downstream irrigation works developed and improved. However, there have been no major improvements in channel alignments.

Three major ancient reservoirs are fully functioning today. The Parakrama Samudra in its present form is a result of a connection of three original reservoirs. The oldest, northern basin - the Thopawewa, the middle basin - the Eramudu Wewa and the southern basin - the Dumbutulla Wewa; the latter two reservoirs being constructed during the reign of King Parakrama Bahu. The southern basin receives water from a channel from the Amban Ganga, regulated by an anicut at Angamidella.

Minneriya tank is believed to have been constructed by King Mahasena (273-303 A.D.). The tank was restored to the present status in 1903 and subsequently improved and enlarged in 1953.

Kandulla tank was known to be in working order in 1680 A.D. The reservoir was probably constructed by King Mahasena (273-303 A.D.) and repaired and restored by Vijeyabahu (1055-1110 A.D.) and finally improved upon by Parakrama Bahu (Arumugam, 1969). The present restoration commenced in 1958. It impounds water from the Gal Oya and Alut Oya and also receives water from the Minneriya - Kantalai Yoda Ela.

5.2 Justification and rationale for modern development

At the time of initiation of the idea of the diversion of the Mahaweli Ganga and the development of the basin, together with the Maduru Oya Basin and that of others in the North and North Central Provinces of Sri Lanka, the population of the island was 11.8 million. The actual growth of the population was far exceeding the trends based on census in the latter part

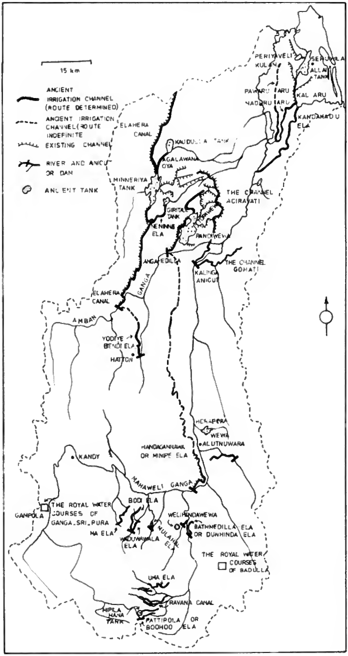


Figure 20. Ancient irrigation works of the Mahaweli Basin (from Hunting Survey Corporation, 1962).

of the century (Fig.21). However, the present rate of growth which stands at 1.7 (1975-1982) is much lower than that of 3.1 (1965-1976) when the project was being planned.

To meet the demand for food for the increasing population as well as for other subsidiary demands such as power, the agricultural resources of the land - in particular in the dry zone - would have to be developed. Most of the ancient civilizations were centred in the dry zone, which was agriculturally developed. For reasons which are still not well understood, the dry zone was gradually abandoned and the population centres shifted to the wet zone. This process was accelerated with the introduction of cash crops by the colonial powers. The abandoned dry zone area was soon overgrown with jungle and diseases such as typhoid and malaria plagued the region; the gradual breakdown of population centres in the dry zone could have been a result of these epidemics.

These epidemics were controlled since the Second World War with the introduction of pesticides. Since the population in the wet zone has been growing rapidly in this century, it has become imperative that attempts be made to redevelop the once prosperous dry zone. The post-independent governments therefore commenced the redevelopment of the dry zone, initially through the restoration of the ancient irrigation works.

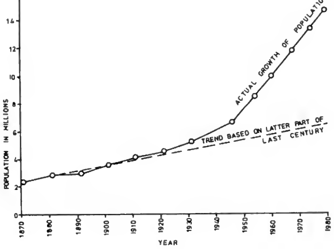


Figure 21. Population changes in Sri Lanka (modified from UNDP/FAO Report, 1969).

Such developments and subsequent settling of these lands enabled the country to cut down on its food imports the value of which was nearing 50% of the total import expenditure of the country.

The dry zone agricultural area is almost entirely dependent upon irrigation and further development could be assured only with a reliable water supply. A reliable water supply would not only bring fresh areas under the plough, but would also enable cultivation throughout the year. Apart from food, the pressure for increased electric power was mounting, not only because of the increase in the population but also because of the industrialization which essentially commenced in 1960. The projected demand for electricity (Fig.22) necessitated harnessing of the hydroelectric potential of a number of rivers.

If the agricultural production was to keep pace with the growing population, the irrigation development was the only way of achieving it. This would be done in the first instance by ensuring an adequate supply of water to the existing systems, and secondly by expanding irrigational facilities to bring new areas under cultivation. It is in this context that the Mahaweli Ganga Development Scheme was proposed with the aim of attaining self-sufficiency in rice and highland crops and to meet the projected extensive demand for hydropower.

5.3 Initial planning

The earliest detailed survey of the Mahaweli Basin was carried out by Hunting Survey Corporation, as a result of an agreement made by the Canadian and Sri Lankan (then Ceylon) governments through the Colombo Plan Administration. The Mahaweli Basin study was one of the three river basin studies undertaken under this agreement. The report on the Mahaweli Basin was presented in 1962 to the Government. The survey provided an inventory of land and water resources of the basin, and provided a basis for evaluation of the potential for development, and preparation of tentative plans for the future use of land and water resources.

The availability of this detailed study may have prompted many political leaders who had interests in irrigational works, to give serious consideration to harnessing the resources of this river basin which covered one-sixth of the island. By the early 1960s it was generally accepted that the vast water resource of the Mahaweli Ganga had to be harnessed effectively. It is in this context that the then Ceylon Government requested assistance from the Special Fund of the United Nations to survey the Mahaweli Ganga Basin and the dry zone areas in the North and Central Provinces of the island in order to provide basic information for a plan to develop the land and water resources for irrigation and hydropower. The final agreements were signed on 12 October 1964 between the Government of Ceylon, the United Nations Development Programme and the Food and Agriculture Organization of the United Nations.

The initial survey was carried out in two stages between March 1965 and February 1967 and included the Mahaweli Basin, Maduru Oya Basin and the rivers of the West side of the North and Central Provinces.

The Master Plan envisaged to utilize 5,800 x 10^6 m^3 of water of the Mahaweli and its tributaries, supplemented by further 1,111 x 10^6 m^3 of water from Maduru Oya and the rivers of the North-Central Province. The potentially usable resource of 6,911 x 10^6 m^3 per year was considered sufficient to irrigate 285,000 ha of paddy throughout the year, or 530,000 ha of alternate crops such as cotton and groundnuts.

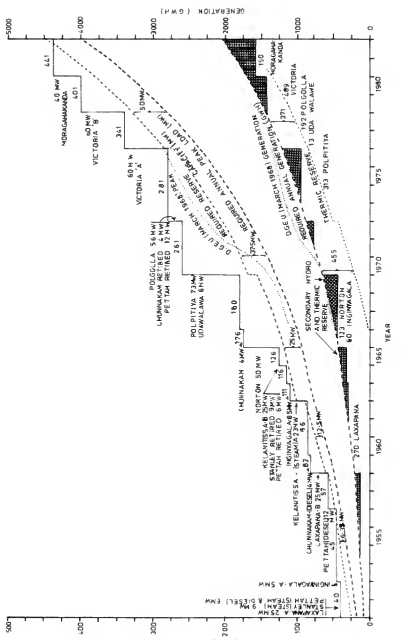


Figure 22. Hydropower demand (projected) and development from 1951 to 1982 in Sri Lanka (from UNDP/FAO Report, 1969).

Of the total grassland area of 2.53 x 10^6 ha in the project, the total suitable land area for irrigation was estimated as 610,000 ha, of which 122,000 is already under cultivation. Nearly 90% of the latter land is irrigated, the remainder being used for rain-fed crops.

The proposed scheme was expected to bring under command 366,000 ha of which 266,000 ha would be underdeveloped land, of which about 150,000 ha or 56% would be in the Mahaweli Ganga and Maduru Oya Basins and the remainder would be in the north-central part of the country.

The proposal to meet the above demands contained the impoundment of 15 reservoirs, 11 of them with hydropower stations with a total installed capacity of 508 megawatts and with a total output of firm power of 2,037 million kwh per annum.

The overall project was to be completed in three phases, each phase with its own set of projects, spanning a thirty-year period. Each phase was to take into consideration the changes in demand for power, irrigation needs, etc., with time and was to be independent of each other in execution and subsequent evaluation.

The three phases suggested were:

(a) Phase 1: 3 Projects - Polgolla Diversion (1969-1973)

Victoria-Minipe Diversion (1973-1977)

Moragahakanda Multipurpose Unit (1977-1980)

In this phase an estimated 133,000 ha was to be irrigated, of which 56% would be under new irrigation. The hydroelectric capacity envisaged was 200 megawatts, capable of producing 820 million kwh of energy per annum.

(b) Phase II: Completion of the development in the Mahaweli and Maduru Oya basins, having met the water requirements of systems A and B (see also Fig.24)

(c) Phase III: Irrigation of land in the north-central part of the country and completion of hydropower development of the Mahaweli Ganga and its tributaries.

Total irrigated area would be 14,000 ha of which 76% would be under new irrigation.

It was envisaged that on completion of the scheme the agricultural production will: match the expected population increases; satisfy the expected rise in the demand for agricultural produce per caput; minimize the food imports and be a net exporter for certain agricultural produce; and increase the farm income. The major works of the Master Plan are also summarized in Table 17.

5.4 The accelerated Mahaweli development

The first project of Phase I was completed when the country was faced with steep inflation in 1973, primarily due to the oil price hike. The

Table 17

Summary of major works and the land area to be irrigated under the different phases of the Master Plan (1965-69) of the Mahaweli Development Scheme

Projects	Land area Irrigated – ha		Location[a] (system)	Hydropower		Cost (Rs[b]) (in million Ceylon rupees)	Benefit	
	Existing	New		Capacity megawatts	Power generated million KWh		Rs.	% rate of return
Polgolla Diversion (1969-73)	41 460	34 150	H.1	40	200	576	130	17
Victoria-Minipe Diversion	5 690	30 080*	C & E	120	470	676	118	13
Moragahakanda (1977-80)	11 400	10 560	A,D & H	40	150	298	42	12
Mahaweli and Maduru Oya Basin	8 540	85 000	A & C	15	48	920	812	20
Development in North Central Area	33 000	106 000		293	1 169	3 113		12

a – location as in Fig. 24;

b – estimates made in 1969, extracted from UNDP/FAO, 1969 government changed in 1977, when 40% of the country's import bill was being spent on food imports and unemployment was in the region of 20% of the normal workforce (Anon., 1978). The rapidly rising inflation also indicated that the later the date of completion of the scheme, the higher would be the ultimate cost. According to one estimate the construction cost could double over a delay of eight years. It was in the light of this situation that the new government reviewed the project and made a policy decision to accelerate the Mahaweli Ganga Development Programme by telescoping the thirty-year planned programme to a six-year programme, commencing in 1979.

The Accelerated Mahaweli Ganga Development Programme did not alter the basic infrastructure of the original Master Plan, but the area to be developed was brought down to 140,000 ha in the Mahaweli Ganga and Maduru Oya Basins and an additional 23,000 ha in the Kalawewa Basin (Figs.23 and 24). The reservoirs to be constructed are the Kotmale Reservoir, Victoria Reservoir, Ulhitiya-Rathkinda Reservoir and Maduru Oya Reservoir (Table 18). The interconnections of the Mahaweli Ganga with the adjacent waterways and the envisaged water distribution pattern of the Mahaweli Ganga Diversion and Development Programme is schematically shown in Figure 25. As a result of the proposed acceleration, instead of sequencing the programme of financing the construction, maintenance and operation, settlement and agriculture, hydropower generation and distribution, community development and infrastructural services, the government has decided that the major aspects be carried out simultaneously. Expectedly, many problems are bound to arise in such a telescoping of events, particularly with respect to the nature of colonization. Therefore, as an important aspect of the planning and implementation, considerable flexibility is permitted and continuous evaluations are made and necessary adjustments carried out.

5.4.1 Environmental considerations

Although some of the present trends of human endeavour bring man into direct conflict with wildlife, the extremely old traditions, associated with the spread of Buddhism in Sri Lanka have undoubtedly resulted in a great concern for preservation of wildlife and their habitats. Such concern is often expressed openly by the populace and endeavours are made in all quarters to preserve this heritage in the context of the modern age.

The Accelerated Mahaweli Ganga Development Programme undoubtedly will come to fruition only with the destruction and/or clearing of a vast area of land of its natural forest vegetation, and the subsequent introduction of monocultural practices on these lands. It is heartening, however, that considerable attention has been paid in the scheme to preservation of wildlife.

In the original Master Plan an approximate area of 120,000 ha was set apart for forest and wildlife resources. This area has been extended by a further 52,000 ha through the creation of another national park. Altogether there will be four national parks in the Mahaweli Basin and adjacent areas (Table 19). These reserves undoubtedly would help in the preservation of the endemic species (8 fish species, 4 amphibians, 19 reptiles, 8 birds and 3 mammals) and the several endangered species inhabiting the plains of the Mahaweli Ganga, as well as 53 species of endemic plants (TAMS, 1980).

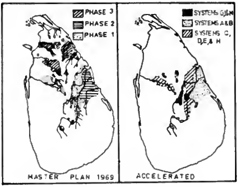


Figure 23. Scope of the development scheme as envisaged in the Master Plan of 1969 and that of the Accelerated Mahaweli Ganga Development Programme (Anon, 1978).

Table 18

Characteristics of major reservoirs being established under the Accelerated Mahaweli Development Programme (Sri Lanka, 1979 and NEDECO, 1979)

Reservoir	Catchment Km^2	Capacity $x\ 10^6\ m^3$	Reservoir level (m) Full	High flood	Max. drawdown	Surface Area ha
Kotmale	544	174	728.5	729.5	664.5	520
Victoria	1 870	728	-	-	-	1 300
Maduru Oya	453	467	95.5	-	83.0	3 480
Randenigala	2 333	860	232.0	-	200.0	2 350
Ulhitiya-Rathkinda	280	98	106.7	-	-	2 020
Moragahakanda	782	686	195.0	-	170.0	4 050

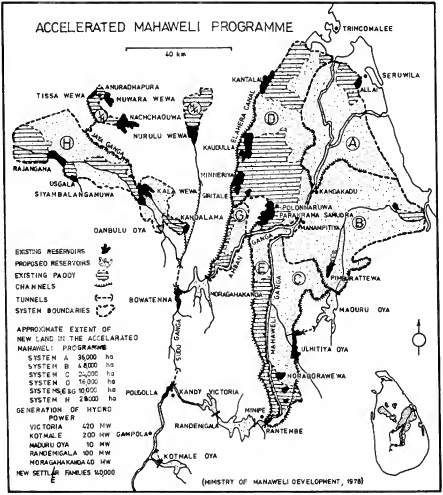


Figure 24. Major features of the Accelerated Mahaweli Ganga Development.

Table 19

The proposed national parks of the Accelerated Mahaweli Development Programme (data from Sri Lanka, 1983)

Park	Area (ha)
Somawathiya National Park	52,000
Flood Plain National Park	20,000
Wasgamuwa National Park	72,000
Maduru Oya National Park	52,000

—/o—

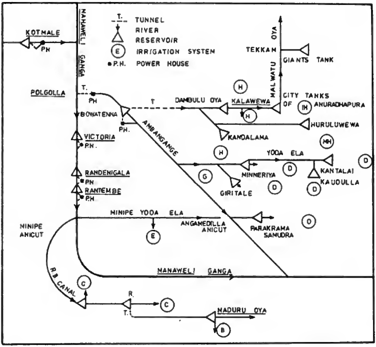


Figure 25. Schematic representation of the water distribution management in the Accelerated Mahaweli Ganga Development (Sri Lanka, 1983).

Consideration has also been given to the fuelwood requirements of the increasing population of the project area, and special areas have been reserved for fuelwood plantations. In the same context, measures have been taken to preserve the forest cover in the upper catchment of the Mahaweli Ganga and also to restrict activities such as the cultivation of seasonal crops like tobacco on steep, degraded slopes which results in soil erosion and alleviate sedimentation of rivers and reservoirs.

5.4.2 Sedimentation

Useful life of a reservoir is determined by the rate of sedimentation and the rate of sedimentation is dependent on the rate of sediment input by river or rivers entering the reservoir.

The ancient reservoirs of the Mahaweli Basin have existed until now without a significant loss in their storage capacities. Data available on sediment transport of the Mahaweli Ganga are scanty. NEDECO (1979) computed the annual transport of sediment at two points in the river and in Amban Ganga (Table 20).

Using the above figures, the yield of sediment in the catchment areas has been computed. It averages 300 m^3/km^2/annum in the main river as compared to 100 m^3/km^2/annum in the tributaries.

Steps are being taken to reduce this sediment yield further through cultural practices. For example, plantation of annual crops on the slopes of the upper catchment have been prohibited and reforestation of the reservoir catchment is in progress.

5.4.3 Settlements, agriculture and infrastructural development

The detailed projected land-use pattern of the Mahaweli Basin and Maduru Oya Basin are shown in Figure 26. The settlement plans envisaged under the Accelerated Mahaweli Development are different from those hitherto adopted for other schemes. The objective of the pattern of settlement is to provide a scope for the development of well-knit communities, and is to be carried out on the principle of 'cluster' settlements. Under the Accelerated Mahaweli Programme a steep increase in the production output per unit land area is also envisaged. The tentative estimated production of the major crops under the scheme is given in Table 21.

Table 20

Expected annual load of sediment transported in the Mahaweli and its major tributary (from NEDECO, 1979)

River	Location	Catchment km^2	Suspended load tons/yr	Bed load tons/yr	Total tons/yr
Amban Ganga	Elahera	772	59 000	59 000	118 000
Mahaweli Ganga	Gurudeniya	1 344	336 000	336 000	672 000
Mahaweli Ganga	Peradeniya	1 108	255 000	255 000	510 000

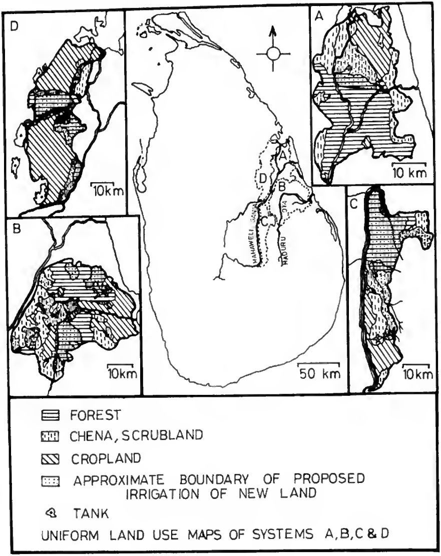

D
A
B
C
MAHAWELI GANGA
MADURU OYA
10km
10 km
10km
10km
50 km
FOREST
CHENA, SCRUBLAND
CROPLAND
APPROXIMATE BOUNDARY OF PROPOSED IRRIGATION OF NEW LAND
TANK
UNIFORM LAND USE MAPS OF SYSTEMS A,B,C & D

Figure 26. The existing and proposed land use pattern of systems A, B, C & D in the Accelerated Mahaweli Ganga Development (modified from Tams, 1980).

During the planning and execution of the project, the following major aspects have been considered in detail in the Master Plan (UNDP/FAO, 1969), as well as in the re-evaluation carried out in 1977-79 for the acceleration of the scheme (NEDECO, 1979): hydrology, hydropower generation, human settlements, agricultural production, other facilities essential for human life such as roads, health care and some others. However, little attention was paid to the fisheries in the future reservoirs. As far as the author is aware, the only mention of fisheries activities in official publications were made in 1979 (Sri Lanka, 1979) and in 1983 (Sri Lanka 1983), when it was stated that the Inland Fisheries of Victoria Reservoir would be developed to yield 1,500 tons per year. In order to achieve this target the entire reservoir bed would have to be cleared of all vegetation prior to impoundment. It was also mentioned that a fish yield of 2,950 tons per year was expected from the Mahaweli Development Programme. However, fisheries was not included in the overall cost-benefit evaluation of the project.

5.4.4 Development of fisheries - Planning considerations

On behalf of the United States Government, a group of consultants, "Tippetts - Abbett - McCarthy - Stratton (TAMS)", was called upon to provide an environmental assessment for the project. This also included fisheries considerations.

Recommendations made by TAMS (1980) and by other fisheries scientists were not heeded. One of such recommendations concerned bush clearing prior to reservoir flooding. It is accepted that if there are no major irrigational and/or hydraulic requirements, it is advantageous not to clear 20 - 25% of the reservoir bed (Bhukaswan, 1980). Such areas, though hindering fishing activities, would provide shelter from predators, an additional food resource and breeding areas for many fish. The decaying vegetation would continue releasing nutrients into the water, thus enhancing the aquatic production (Oglesby, 1977).

However, what happened was that in the Accelerated Mahaweli Development approach, all vegetation was completely cleared and burnt before impounding the area. But Sri Lanka offers an excellent example of the advantage of having vegetation in the reservoir. In Parakrama Samudra, one of its three distinct basins is devoid of decaying vegetation with the result that nobody is fishing there. In the other two basins, which have large amounts of vegetation, fishermen are very active in spite of the difficulties with moving around and with setting and removing fishing gear.

It has also been felt that in the settlement pattern and land allocation, some land near reservoirs should have been reserved for families to be involved in the fisheries. As such, allotees who are likely to take up fishing will do so only as a complementary activity to farming and consequently it will take a few years before they develop fisheries expertise.

In addition to the yield of 2,950 t per year from capture fisheries on reservoirs, the government is now also encouraging development of aquaculture in the area with a view to not only meeting the protein requirements, but also as a means of providing additional employment (Sri Lanka, 1983).

Table 21

Estimated annual production of major crops

Crop	Average yield ha^{-1} kg	Total output[a] '000 tons	Accelerated Programme
Paddy	3 560	1 160 (milled rice)	747
Sugar cane	35 640	660	289
Cotton	1 883	29	75
Groundnuts	2 008	249	–
Chillies	1 255	128	–
Bombay Onions	12 550	71	–
Vegetables	8 662	71	–
Maize	3 770	256	–
Pulses*	–	98	121

a – Master Plan projection

* – green gram, black gram and cowpea

Table 22

The contribution of the major and medium-scale reservoirs and villus of the Mahaweli Basin (including Maduru Oya) to the total Sri Lanka inland fish production (in metric tons)

Year	Reservoirs Major	Medium	Villus	Total	Island Total	% Contribution
1970	917.8	40.0	200[a]	1 157.8	8 200	14.1
1971	860.1	38.0	160[a]	1 058.1	8 000	13.2
1972	889.9	42.0	280[a]	1 211.9	8 300	14.6
1973	825.0	35.0	280[a]	1 140.0	6 900	16.5
1974	840.0	36.0	300[a]	1 176.0	7 500	15.7
1975	1 941.0	62.0	300[a]	2 303.0	13 100	17.6
1976	2 024.4	58.0	300[a]	2 382.4	12 300	19.4
1977	1 565.7	44.0	300[a]	1 909.7	12 900	14.8
1978	1 706.9	65.0	405.2	2 177.1	16 400	13.3
1979	2 142.4	60.2	380.1	2 582.7	17 100	15.1
1980	3 183.2	48.5	562	3 793.7	19 900	19.1

a – estimated

6. MAHAWELI GANGA BASIN DEVELOPMENT AND FISHERIES

The backbone of the existing fisheries of the Mahaweli Basin is the reservoir fishery, which contributes significantly to the total fish yield of Sri Lanka. The development of the reservoir fishery in the Mahaweli Basin and its contribution to inland fisheries is shown in Table 22.

The hydrological development of the basin is likely to affect fish yield and fisheries in a number of ways:

(a) by manipulation of discharges, which will especially affect the existing reservoir fisheries and those on floodplains (villu);

(b) by providing 24,000 ha of lacustrine water bodies (TAMS, 1980), 360 km of main channels and 4,080 km of distributory channels which will become available to fisheries (Anon., 1978);

(c) by allowing the penetration of seawater further up-river during low discharge periods;

(d) by the impact of modified nutrient discharges on sea life.

6.1 Reservoirs

6.1.1 Existing fisheries

Fish production in lacustrine waters is closely linked to the nutrient availability (Ryder, 1965; Oglesby, 1977; Welcomme and Henderson, 1976). It is predicted that as a result of the Mahaweli Ganga Development the retention time in the existing reservoirs in the basin will decrease appreciably, i.e. by nearly half in the case of Kaudulla and Kantalai reservoirs. Recent limnological studies on the Parakrama Samudra (Schiemer and Duncan, 1983) have indicated that even under the existing regime the retention time is insufficient for the completion of the production cycle of some planktonic organisms. A further shortening of retention time may worsen the situation, resulting in a lower phytoplankton and zooplankton production and therefore in a reduced food supply for fish.

On the other hand, TAMS (1980) has suggested that although the flushing rates would increase, the availability of nutrients in the system should be adequate to maintain a high aquatic productivity. But Gunatilaka (1983) has shown that in the Parakrama Samudra, the currently most productive reservoir of the basin, the phosphate availability is limiting. The data available for this reservoir may be indicative of the level of fish production which we may expect in the new reservoirs.

The importance of water level fluctuations on the abundance and yield of commercially valuable fish species in floodplains (Welcomme and Hagborg, 1977; Dudley, 1979) as well as in lacustrine (Marshall, 1982; Beam, 1983) fisheries is well documented. In the case of the Parakrama Samudra fishery it has been shown that the yield of the cichlid O. mossambicus was positively correlated to the degree of fluctuation of the water level two years earlier (De Silva, 1985a).

According to NEDECO (1979) the development of the Mahaweli Basin should not result in any significant changes in water level fluctuations as compared with those prior to the diversion of the river. The data available seem to suggest the contrary. Figure 27 suggests that the

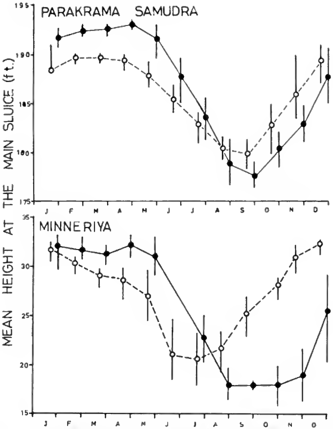


Figure 27. The mean monthly water level at the main sluices of the Parakrama Samudra and Minneriya reservoirs prior to and after receipt of Mahaweli waters in 1976.

Table 23

Fish yield in kg/ha/annum of the existing major reservoirs prior to 1976 (pre-) and after 1976 (post-)

Reservoir	Total		O. mossambicus				Others			
	Pre-	Post-	Pre-	%	Post-	%	Pre-	%	Post-	%
Parakrama Samudra	323	355	202	62.4	260	73.2	121	37.4	95	26.9
Minneriya	n.a.	200	n.a.	n.a.	136	67.8	n.a.	n.a.	64	32.1
Kaudulla	n.a.	198	n.a.	n.a.	123	61.9	n.a.	n.a.	75	37.8

n.a. - not available

degree of fluctuation of the water levels in the Parakrama Samudra and Minneriya reservoirs for which data are available have changed significantly to that of the pre-diversion period.

For the time being, the yield predictions can only be based on a comparison of yield figures from the existing reservoirs for the years prior to the receipt of Mahaweli waters with those for the post-diversion period (Table 23). Based on this the expected yield from these reservoirs from the existing fishery is 2,800 t/annum.

6.1.2 New reservoirs

The Mahaweli Ganga diversion and the consequent development of the Basin, which is carried out in conjunction with the Maduru Oya Basin development, will result in the creation of large areas of lacustrine bodies. Their hydrological characteristics are summarised in Table 24.

The total reservoir area to be created approximates nearly one-fifth of that of the existing major reservoirs (Mendis, 1977; Fernando and De Silva, 1984). Of that, 3,770 ha will be located in the hill-country and have primarily a hydroelectric power production function. These reservoirs will be deeper than most of the other reservoirs. In these reservoirs the temperature could fluctuate as much as 10°C per day, and because of their depth they are likely to develop a strong thermocline and oxygen deficiency in deep water. Similar phenomena have been reported, for example, for Indian reservoirs (Ganapati, 1973). On the other hand, detailed limnological studies of Parakrama Samudra have indicated that the shallow, low-country Sri Lanka reservoirs are unlikely to develop and retain a strong thermocline and/or chemical stratification for long (Bauer, 1983).

6.1.2.1 Stocking

There have been no firm plans yet regarding the stocking of these reservoirs, although some views have been expressed by individuals interested in the development of the reservoir fisheries industry.

Table 24

Some characteristics of perennial, major reservoirs resulting from the Mahawell Ganga Development (data from TAMS, 1980)

Reservoir	Storage capacity mcm	Surface area ha	Mean depth m	Year of Impoundment
Kotmale	120	520	23.1	1984
Victoria	624	1 300	48.0	1984
Randenigala	810	1 950	41.5	1985
Moragahakanda	280	1 800	15.5	-
Rotalawela	70	2 500	2.8	-
Kandakadu B	-	2 900	2.5	-
Ulhitiya Oya/ Rathkinda	122	2 020	6.0	1982
Maduru Oya	536	3 480	9.7	1983

- not yet impounded or no data

Indian experts of the Ministry of Fisheries (Dr. A. Sreenivasan and Mr. K. Chakrabarthy) are of the view that the downstream reservoirs should be stocked with Indian major carps, viz. rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigal*) and catla (*Catla catla*). Some of the older reservoirs have been repeatedly stocked with Chinese major carps since 1976, and with common carp since before 1976. However, there is no evidence that these species have established themselves in the major reservoirs, and their returns from the stockings have been almost nil (Fernando and De Silva, 1984). The likely reasons for this lack of success have been discussed by Fernando and De Silva (1985) and De Silva (1985a) If a stocking and harvesting procedure is to be carried out, the input costs are going to be very high, and without reasonable returns. Logistically, it would be more advantageous to utilize the facilities available and those forthcoming for the stocking and harvesting programmes of the sesonal tanks (FAO Report, 1982). This programme is to be extended to the Mahaweli Basin.

The author is of the view that the downstream reservoirs will follow a pattern already in existence in the dry zone major reservoirs, in that *Oreochromis mossambicus* will begin to dominate the fishery. It would be advantageous to stock this species together with *O. niloticus*, to enable a more efficient utilization of the likely high levels of algal production which will be encountered in the early post-impoundment period of reservoirs (Bhukaswan, 1980).

6.1.2.2 Yield estimates

Fish production of the hill-country reservoirs is likely to be significantly different from that of the downstream area and hence has to be considered separately. Estimates of potential fish production for the different reservoir types were made by Mendis (1965) and Oglesby (1980) and for those in the Mahaweli Basin by TAMS (1980) (Table 25).

Table 25

Estimates of potential yield per annum for different types of water bodies (kg/ha)

Reservoirs	Mendis (1965)	Oglesby (1980)	TAMS (1980)
Hill Country Res.	56	-	20 - 35
Lowland Res.	671	111 - 357	100 - 300
Villus (Floodplain Lakes)	112	-	50

The TAMS (1980) estimates were specifically made for the Mahaweli Basin reservoirs (Table 26). They, however, based their estimates on an equation derived by Wijeyaratne and Costa (1981) for Sri Lankan reservoirs which was based on one year's yield data from 7 reservoirs of which 4 were not taken into consideration on the unauthenticated suggestion that the available statistics for the latter were erroneous. The basis of the derivation of the yield/MEI relationship is contrary to the basic concepts put forward by Ryder (1982) and did not meet the necessary requirements of the model. The present author (De Silva, 1985a) has shown in detail that the MEI concept is not applicable to Sri Lankan reservoirs, both qualitatively and quantitatively. Therefore, the extension of the findings of Wijeyaratne and Costa (1981) and derivation of potential yields from specific reservoirs based on electrical conductivity measurements as carried out by TAMS (1980) is questionable. A more realistic method of estimation of the potential yield, in the light of the lack of a suitable model, would be to use the existing yield values of those reservoirs and make an extrapolation. The same approach was adopted by Oglesby (1980) for yield prediction for Sri Lankan reservoirs. Reliable estimates of the existing production of the reservoirs are only available for 4 reservoirs in the Mahaweli Basin and adjacent areas (Table 27), and the mean yield amounts to 372 kg/ha/annum. However, the mean yield for reservoirs over 2,000 ha was 262 kg/ha/annum and for those less than 1,000 ha was 710 kg/ha/annum.

Table 26

Predicted fish yields for the major reservoirs
as suggested by TAMS (1980)

Reservoir	kg/ha/annum	Total yield (t)
Kotmale	25	13.0
Victoria	22	28.6
Randenigala	34	66.3
Moragahakanda	103	185.4
Rotalawela	250	625.0
Kandakadu Barage	319	925.1
Ulhitiya/Rathkinda	145	292.9
Maduru Oya	124	431.5

Table 27

The average production of existing reservoirs on lowland plains

Years	Reservoir	Production kg/ha/yr
1975 - 82	Parakrama Samudra	380
1976 - 82	Minneriya	200
1979 - 82	Kaudulla	198
1980 - 82	Pimburettewa	710

Using the above figures and estimates of Mendis (1977) for floodplain lakes and hill-country reservoirs the estimated total fish production from the newly impounded perennial reservoirs as a result of the Mahaweli Diversion Scheme would be 3,539 t/annum. The details of the breakdown are given in Table 28.

Table 28

Estimated fish production from the new perennial reservoirs resulting from the Mahaweli Diversion

Reservoir	Production/annum (t)	
	TAMS	Present
Kotmale	13.0	29.1
Victoria	28.6	72.8
Randenigala	66.3	109.2
Moragahakanda	185.4	471.6
Rotalawela	625.0	655.0
Kandakada	925.1	759.8
Ulhiti Oya/Rathkinda	292.9	529.4
Maduru Oya	431.5	911.8
Total	2,567.8	3,538.7

The present estimate is 62% higher than that of TAMS (1980), but is in agreement with those based on estimates of Mendis (1977) and Oglesby (1981).

6.1.2.3 Yield from untapped resources

All estimates of fish production from reservoirs have taken only the existing fisheries into consideration, and by and large refer to a mono-specific fishery. The preliminary work of Hofer and Schiemer (personal communication) based on experimental fishing on the Parakrama Samudra has indicated the presence of considerable standing stocks of indigenous minor carp, and the author's own personal observations have indicated significant resources of indigenous carnivores, which at present occur in catches only rarely. In two reservoirs the fishery for minor cyprinids which has existed for over a decade has indicated that a fishery for minor carps could exist together with that for the cichlids without apparent detrimental effects on the latter.

The available data, though of a preliminary nature, suggest a yield of 20-50 kg/ha of minor cyprinids and 10-25 kg/ha of carnivores. With the lower level of production the potential yield of this untapped resource would be about 680 t/annum from all the major reservoirs of the lower plains of the Mahaweli Basin.

The importance of these resources has gone unnoticed by a number of missions which dealt with inland fish production in Sri Lanka. The utilization of this resource would involve only small capital expenditure. Although it is questionable whether minor cyprinids would be preferred fresh, they could be dried. There is a market for such dried fish. It could also be made into fish meal which could form the base for the future fish feed industry.

The carnivorous species are highly priced and are preferred fresh. There is no difficulty for marketing them.

6.2 Villus

The manipulation of the Mahaweli Ganga flood peaks and the dry season flow is bound to result in an overall decrease in the floodplain including the villus, which is estimated to become approximately halved to 6,400 ha. The direct effect on the fisheries will be due to the corresponding loss in the floodplain area. Anticipating a yield of 50 kg/ha/annum, TAMS (1980) estimated that the yield from the villus and floodplains would decrease by about 320 t/annum.

In the light of the availability of more reliable production statistics the TAMS (1980) estimates of the potential yield of 320 mt per annum from the villus need to be reconsidered. There is no reason to believe that the reduction of the villu area as a result of the Mahaweli Ganga Basin development would affect their fish yield. The productivity could increase due to the overflow of the excess fertilizer from the increased cultivation in the river basin. Based on the present mean production of 133.0 kg/ha/annum. However, bearing in mind (Table 16) that the mean yield is not a true reflection of the potential due to the present under-exploitation of the resource, a realistic yield of 150 kg/ha/annum or 960 t/annum is suggested.

The loss of floodplains is likely to result in the loss of some spawning grounds for most of the indigenous species of commercial importance for the reservoir fishery, particularly *Labeo dussumieri*, *Puntius* (= *Barbus*) *sarana*, and in changes in the migratory pattern of a number of indigenous forms. The changes observed in the yield of *Puntius sarana* and *Labeo dussumieri* for the pre- and post-receipt of Mahaweli waters are shown in Figure 28. There is a drop in their contribution to the fishery and also a shift in the peak periods of their occurrence in catches (see also Table 23, 'Other'). It cannot be ruled out that this decline is a result of the impact of the Mahaweli Basin development.

6.3 Estuarine and sea fishery

The existing fishing in the estuarine portion of the Mahaweli Ganga is represented primarily by the subsistence fishery for shrimp. The peak shrimp catches occur in March to May. Off the Trincomalee Bay about 150 fishermen operate and the average daily catches range from 20 to 180 kg/day depending on the season.

The tidal influence in Mahaweli Ganga extends about 6 km from the coast. The water regulation and diversion due to the Mahaweli Ganga development scheme is likely to reduce the river discharge by about 50%, both in the dry season as well as during the wet seasons. The reduced flow is likely to result in tidal influence to be felt higher up the estuary, thereby increasing the nursery area available for larval shrimp.

The reduced water discharge and intensity of flood peaks are likely to reduce the nutrient discharge into the coastal area, and to increase the pesticide levels discharged into the sea.

Recently, appreciable populations of whales have been recorded off Trincomalee and a programme is being prepared to commence scientific studies on their biology as well as to make them a tourist attraction. The lower nutrient discharge into the sea might have some effect on the

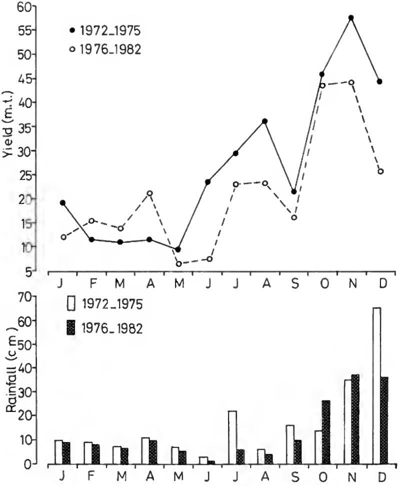


Figure 28. Seasonal changes in the indigenous species fishery in Parakrama Samudra (1972-1975: Prior to Mahaweli water input; 1976-1982: Mahaweli water input).

whales through lowering the aquatic productivity of the coastal sea, although it is also possible that nutrient levels will stay relatively high due to the intensive use of fertilizers in the catchment.

6.4 Aquaculture

The development of the Mahaweli Basin will result in an increase in the number of human settlements and in a population of one million by 1990 in the basin. The recommended animal protein intake is 60 g of fresh fish per day (Anon. 1983). The total animal protein requirement for the population by 1990 would be approximately 21,900 t. Even at the present level of consumption of 15.1 kg/year the requirement would be around 15,000 t/year.

The potential total yield from the capture fisheries of the major reservoirs and villus of the Mahaweli and Maduru Oya basins is estimated to be 9,058 t (Table 29). This estimate has not included the other areas of development of the scheme, although the expected population growth is for all the areas coming under the Accelerated Mahaweli Ganga Development. The major population centres are expected to be located in the Mahaweli Ganga and Maduru Oya basins and will account for approximately 70% of the expected population growth. The capture fishery, therefore, is unlikely to meet the demand and a considerable proportion of the short-fall has to be met by aquaculture.

Table 29

Potential annual yield from the capture fishery of the Mahaweli Basin

Type	Yield tons
Existing major reservoirs*	2,800
New major reservoirs	3,538
Existing medium - scale reservoirs	1,060*(TAMS,1980)
New fish resources (sectin 6.1.2.3)	680
Villus	960
Others (e.g. riverine)	20
Total	9,058 per annum

* Including Pimburettewa and Kantalai reservoirs

6.4.1 Extensive culture systems - Seasonal tanks

The Mahaweli Basin has approximately 4,000 ha of seasonal tanks which dry up for 3-4 months every year. The potential use of these water bodies, most less than 10 ha in surface area, was first identified by Mendis (1965), and reconfirmed by Oglesby (1979). Trials were carried out at the district level to evaluate the potential production of these water bodies during the growing season in 1979/80, 1980/81 and 1981/82. Results of trials in four seasonal tanks of the Mahaweli Basin are summarised in Table 30.

Table 30

Results of production (kg/ha) trials carried out in four seasonal tanks in the Mahaweli Basin (from Thayaparan, 1982)

Tank	Growing Season		
	79/80	80/81	81/82
Kudahatawewa	706.7	840.8	18.0
Thimbirigaswewa	191.6	239.3	70.1
Moragaswewa	-	-	dried
Dehiattawewa	-	-	dried

The maximum production in all trials was 1,414.6 kg/ha. The potential of the seasonal tanks to enhance the fish production has been acknowledged (FAO, 1982).

The programme of stocking and harvesting, mostly utilizing the major Chinese and Indian carps, is to be stepped up further throughout Sri Lanka under the Asian Development Bank Programme (FAO, 1982) which commenced in 1984. This project envisages a yield of 15,000 t during the first five years through stocking and harvesting of 20,000 ha of seasonal tanks, a production of 750 kg/ha/annum.

In this programme it is envisaged to maximize fish production by introducing fast growing, late maturing species to fill all the ecological niches available in the water body. The list of species to be stocked includes the Indian carps *Catla catla*, *Labeo rohita*, *Cirrhina mrigala*, and the Chinese carps *Aristichthys nobilis*, *Hypophthalmichthys molitrix* and *Ctenopharyngodon idella*, supplemented by the indigenous *Labeo dussumieri* and the exotic cichlid *O. niloticus*, if and when needed. All the Indian and Chinese carps and *L. dussumieri* have been spawned artificially in the breeding stations, some since 1976 (Weerakoon, 1979). The exact quantities of each species to be stocked are to be initially based on the results of already completed trials, on the survival and the growth of individual species, as well as on the interspecific compatibility. These observations will be supported by limnological and biological observations to assist in determining the overall stocking rate as well as the ratio of species.

Under the country programme two of the fisheries stations in the Mahaweli Basin, i.e. the Dambulla and Polonnaruwa Fish Breeding Stations, will be improved. There is also a likelihood of a fish breeding centre being located at Madura Oya Reservoir under the Canadian International Development Agency (Director of Inland Fisheries, personal communication). Under such circumstances it is to be expected that a considerable proportion of the seasonal tanks in the Mahaweli Basin is likely to be utilized for fish production, and a reasonable assumption will be that at least 75%

of the 4,000 ha of the available seasonal tank area will be commissioned for fish production by 1988. The expected yield from this resource is around 2,250 t.

6.4.2 Intensive culture

The Buddhist traditions remain one of the main constraints for the development of intensive aquaculture. These traditions are very much preserved in the Mahaweli Basin which has a number of important places of worship for Buddhists and centres of culture for the Sinhalese people.

The likely location of three major centres of fish breeding and the training centre in the Mahaweli Basin are bound to minimize the hindrance to fisheries development brought about by the traditional attitudes of 'do not rear to kill and eat'. It is expected that a reasonable number of settlers will take up intensive pond culture in the area (Hettiarachchi, 1982), with a possible emphasis on polyculture systems with incorporated poultry rearing.

Rice cum fish culture is unlikely to catch on in Sri Lanka as the varieties of paddy used in Sri Lanka need to retain water only for 2-3 weeks and thereafter the rice paddies need only a moist ground. Hence, paddy cum fish culture will have to evolve with changes in varieties of paddy utilized, which at present seem a very unlikely proposition.

6.4.2.1 Cage culture

The availability for large areas of lacustrine water bodies in Sri Lanka has prompted many people to advocate introduction of cage culture, particularly in the large, perennial reservoirs. The first commercial-scale cage culture operations were undertaken in 1980/81 in two major reservoirs, viz. Parakrama Samudra and Udawalawe. The trials were conducted with high stocking densities of O. niloticus, fed intensively on fish meal based on protein rich diets. The results have shown the feasibility of such operations in reservoirs (Wannigama and Weerakoon, 1982). In spite of the good rate of growth, high survival and good food conversion ratio, the present low market price for O. niloticus and for freshwater fish in general does not appear to make cage culture economically viable. However, a 10% to 15% reduction in feed cost would make it viable, and the present research of the Ministry of Fisheries is aimed in this direction.

Amongst the intensive culture operations, the cage culture offers the best prospects for potential small-scale entrepreneurs. With the increasing emphasis and introduction of incentives for aquaculture, prospects for cage culture look bright.

6.4.2.2 Irrigation channels

It is surprising that hitherto no attempt has been made to utilize for fishery purposes the vast number of irrigation channels already available or which will come into being as a result of the Mahaweli Ganga Basin development. The typical nature of irrigation channels is shown in Figure 29. These channels, mostly 0.5 to 1 m in depth, with their mud banks overgrown with vegetation and with changing water level and current speed provide ideal conditions for crayfish species of the family Astacidae (Bardach et al., 1972). The Sri Lankan freshwater fauna does not have any astacid species (Mendis, 1962) and contains only one freshwater species suitable for culture viz. Macrobrachium rosenbergii. This species,

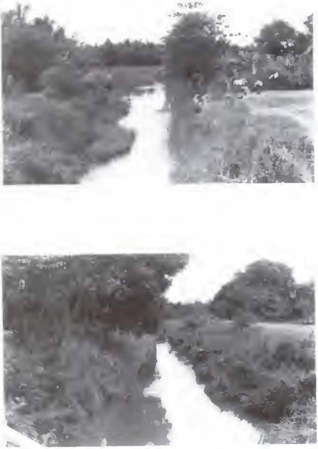


Figure 29. Irrigation channel.

however, needs estuarine conditions to complete its life cycle. Sri Lanka has hitherto not introduced any crustacean species for culture and the possible ecological effects of any suggested introduction will have to be evaluated prior to such introduction.

6.5 Species introductions

Sri Lanka has had one of the highest levels of food fish species introductions in the world relative to its indigenous finfish fauna (Table 3). Nevertheless, there is no evidence to believe that any of these introductions have been harmful either ecologically or biologically, except perhaps the accidental introduction of the cestode Bothriocephalus gowkonensis (Fernando and Furtado, 1963). The introduction of O. mossambicus has led to the development of viable freshwater fisheries, with this species forming the backbone of it. It is interesting to note that most of the introductions which were haphazardly carried out have been unsuccessful and remain as mere book records. Others, notably the major Indian and Chinese carps, are destined to play a major role in the seasonal tank and pond culture programmes, and their potential in the former in particular is already evident from the trials carried out throughout Sri Lanka (Thayaparan, 1982).

6.5.1 Reservoir fishery

Fernando (1965, 1971) advocated the introduction of deep-water herbivorous and carnivorous fish, particularly into the mid- and hill-country reservoirs. More recently, views have been expressed to introduce a zooplankton feeder, to fill in the vacant niche, in low country reservoirs. In this context suggestions have been made that the African clupeids Limnothrissa sp. and/or Stolothrissa sp. could be suitable candidates. The omnivorous Limnothissa was successfully introduced into the African natural lake Kivu as well as into the large reservoir Kariba, from where it has spread downstream into Cahora Bassa reservoir (Petr and Kapetsky, 1983). Stolothrissa, which feeds predominantly on zooplankton, was not successful. Such introductions into Sri Lankan reservoirs could be made only on the basic assumption that there is a sufficient food supply available. Unlike African lakes and reservoirs, which are considerably larger than those in Sri Lanka, the Sri Lankan reservoirs are also characterised by a short retention time and poor zooplankton which represents part of the diet of Limnothrissa, but much of the diet of Stolothrissa. The latter species would probably also fail in most of the shallow Sri Lankan reservoirs, as it prefers the off-shore deep waters of its natural habitat of Lake Tanganyika.

The recent appearance of the halfbeak (Hyporhamphus gaimardi) in some low country reservoirs, including two in the Mahaweli Basin, in sufficient quantity to support 2 to 3 full-time fishermen, may well be the first indication of utilization of the vacant 'zooplankton niche' by an indigenous, but a non-specialized zooplankton feeder in that H. gaimardi feeds on zooplankton, supplemented by a considerable proportion of terrestrial insects. There is also evidence that this species, although typically coastal and estuarine, is breeding in certain reservoirs. If this is true, there is no reason for the introduction of an exotic zooplankton feeder such as an African clupeid.

Amongst the candidate fish suggested for introduction is O. aureus, possibly based on the success of its counterpart, O. mossambicus. More recently suggested candidates are T. sparrmanni, an omnivore and S. galilaeus, a phytoplankton feeder (TAMS, 1980).

In the author's view it will need further biological and ecological investigations before any more introductions of finfish species are made to Sri Lanka. There is no reason to believe that even the introduction of suitable species into the deep hill-country reservoirs in the Mahaweli Basin will result in a viable fishery.

6.6 Research opportunities

The Mahaweli Development is destined to result in the impoundment of 9 major reservoirs, whose characteristics vary in terms of topography, climate and geological formations. The development scheme is also destined to bring about changes in the hydrological regimes of older reservoirs which range in age from nearly 1,000 years to 25 years.

This development scheme therefore offers a system of reservoirs which could be studied from the first day of their impoundment from limnological and fisheries point of view. They offer an ideal opportunity to follow the development of fish populations, both introduced as well as naturally recruited. The close proximity of the reservoirs makes such a comparative study logistically feasible.

So far there has been no initiative, either by the agencies of the government of Sri Lanka or international organizations to launch such a limnological and fishery biological study of the reservoir system. Undoubtedly, isolated pieces of research on these aspects will be carried out by individuals and/or institutions on a small scale, which is unlikely to give the same coherence and understanding of the system as a whole. This ideal opportunity, if lost, will be hard to come by again and will be a loss to the advancement of tropical limnology and fisheries biology and management.

7. CONCLUSIONS

Although the primary purpose of the Mahaweli river basin development and associated construction is not fisheries development, the incorporation of fisheries development in such strategic schemes would be most beneficial as fisheries may provide considerable returns. A case in point is the Ubolratana Reservoir in Thailand, where the return from the fishery surpasses that from electricity generation, although the reservoir was primarily constructed for the latter purpose (see Bhukaswan, in this Volume). The original Mahaweli Ganga Diversion and Development plans did not incorporate the fisheries sector, and the expected returns from this sector were not taken into consideration in the cost-benefit analysis. Nor were they taken into account in the settlement planning which is crucial and pivotal for the proper functioning of the scheme. However, under the Accelerated Mahaweli Development Programme the developmental strategies of the fisheries sector have been taken into consideration under an Environmental Assessment Programme. Some recommendations such as to retain the vegetation of a proportion of the reservoir bed to alleviate the fish production were not heeded. Although the yield from the various water bodies was computed, the results appeared to be not accurate enough for reliable predictions. The Environmental Assessment Programme stressed the need to increase the aquacultural practices.

The present report provides new yield estimates for individual water bodies and suggests possible ways of increasing fish production, in addition to the traditional - mostly monospecific - reservoir fishery which is bound to develop in the new reservoirs. Exploitation of non-traditional varieties, particularly the minor indigenous cyprinids and indigenous carnivorous species, should produce a yield of at least 650 t/annum. The success of such a fishery in the Mahaweli Basin would undoubtedly serve as an example which would be followed in reservoirs elsewhere in Sri Lanka.

While the emphasis on aquaculture development has hitherto concentrated on pond and cage culture, the vast system of irrigation channels which will come into being as a result of the Mahaweli Ganga Development, as well as other river basin development schemes, is still waiting to be assessed. This water resource could well provide a base for an extensive culture of highly priced freshwater crayfish, aimed for the export market.

Introductions of new finfish species are not recommended as the existing species, both exotic and indigenous, should provide a sufficient species diversity for the development and maximization of the inland fishery.

It is also suggested that in river basin development due consideration needs to be given to the settlement pattern, in order to maximize the return from the fisheries sector, especially from reservoirs. A delay in acquisition of the expertise in the art of fishing by settlers who are mostly farmers, and are likely to take up fishing initially at a subsistance level, may result in under-fishing of the peak fish production to be expected to be achieved during the first few years after damming the river.

With the expected development of intensive fish culture practices and reservoir fishery in the Mahaweli Basin the available water resources are likely to meet nearly 70% of the overall recommended animal protein requirements of 21.2 kg/annum/person of the population of the Mahaweli Basin by 1990.

ACKNOWLEDGEMENTS

I am most grateful to the Director of Inland Fisheries, and the Officer-in-Charge of the Polonnaruwa Station, Mr. A. Hettiarachchi, for providing me with data on the existing fishery and to many others of this Division for giving their time to discuss the problems of the fishery. My thanks are also due to Mr. M.A. Jansen, Environmental Officer, Mahaweli Development Authority for providing me with some of the most relevant literature on the Mahaweli Ganga Development Scheme; to Mr.P.Maitipe of the Department of Zoology for making the drawings; to Ms.P.A.Wickremaratne for typing the manuscript; to Mr. B. Abeysundera for his valuable comments on some of the chapters, and finally to my wife, Dr. Celine De Silva for her invaluable criticism.

8. REFERENCES

Arumugam, S., 1969 Water resources of Ceylon. Colombo, Water Resources Board Publication, 407 p.

Bardach, J.E., J.H. Ryther and W.O. McLarney, 1972 Aquaculture: the farming and husbandry of freshwater and marine organisms. London, Wiley-Interscience, 868 p.

Bauer, K., 1983 Thermal stratification, mixis and addective currents in the Parakrama Samudra Reservoir, Sri Lanka. In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, W. Junk Publishers, pp. 27-34

Beam, J., 1983 The effect of annual water level management on population trends of white crappie in Elk City reservoir. Fish.Manage., 3:34-40

Bhukaswan, T., 1980 Management of Asian reservoir fisheries. FAO Fish.Tech. Pap., (207):69 p.

Brohier, R.L., 1934 Ancient irrigation works in Ceylon. Vol.I. Colombo, Ceylon Government Press, 37 p.

------------, 1935 Ancient irrigation works in Ceylon. Vol 2. Colombo, Ceylon Government Press, 43 p.

Central Bank of Ceylon, 1979 Statistical abstracts. Colombo. 316 p.

Ceylon Association of Science, n.d. A survey of potable and industrial waters in Ceylon. Presidential address. Colombo, 28 p.

Ceylon, Department of Census and Statistics, 1969 The Ceylon economic atlas. Colombo, Department of Census and Statistics, 69 p.

Chandrasoma, D. and S.S. De Silva, 1981 Reproduction biology of Puntius sarana an indigenous species and Tilapia rendalli, in an ancient, man-made lake in Sri Lanka. Fish Manage., 12:17-28

Cooray, P.G., 1967 An introduction to the geology of Ceylon. Spolia Zeylan., 31:324 p.

Darlington, P.J., 1957 The geographical distribution of animals. New York, John Wiley, 675 p.

De Silva, S.S., 1983 Reproductive strategies of some major fish species in Parakrama Samudra Reservoir and their possible impact on the ecosystem - a theoretical consideration. In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, Dr. W. Junk Publishers, pp. 183-91

------------, Impact of exotics on the inland fishery resources of Sri Lanka. In Proceedings of the Workshop on Tropical Limnology (Asia/Pacific) and Water Quality, University of Malaya, Kuala Lumpur, Malaysia, Nov. 1982 (in press)

------------, Status of the introduced cichlid Sarotherodon mossambicus (Peters) in the reservoir fishery of Sri Lanka: a management strategy and ecological implications. Aquacult.Fish.Manage., 1:91-102 (in press a)

------------, Observations on the abundance of the exotic cichlid, Sarotherodon mossambicus (Peters) in relation to water level fluctuation in a man-made lake in Sri Lanka.Aquacult.Fish.Manage., (in press b)

De Silva, S.S. and C.D. De Silva, Coastal lagoons. In Ecology and biogeography of Sri Lanka , edited by C.H. Fernando. The Hague, The Netherlands, Dr. W. Junk Publications (in press)

De Silva, S.S. and C.H. Fernando, 1980 Recent trends in the fishery of Parakrama Samudra, an ancient man-made lake in Sri Lanka. In Ecology and development, edited by J.I. Furtado. Kuala Lumpur, Malaysia, Univeristy of Malaya Press, pp. 927-37

De Silva, S.S., P. Maitipe and P.R.T. Cumaranatunga, Aspects of the biology of the euryhaline Asian cichlid, Etroplus suratensis. Environ.Biol.Fish, (in press)

Domros, M., Sri Lanka. Die Tropeninsel Ceylon. Darmstadt, Wissenschaftliche Buchgesellschaft, 298 pp.
1976

Dudley, R.C., Changes in the growth and size distribution of Sarotherodon macrochir and Sarotherodon andersoni from the Kafue flood plains. J.Fish Biol., 14:205-23
1979

Ellepola, W.B. and C.H. Fernando, Hatching and rearing of gouramy (Osphronemus goramy, Lacepede), in the Polonnaruwa nursery. Bull. Fish.Res.Stn.,Colombo, (19):1-3
1968

Evans, D., Threatened freshwater fish of Sri Lanka. Cambridge, U.K., IUCN Conservation Monitoring Centre, 59 p.
1981

FAO, Technical Cooperation Programme, Sri Lanka. A synthesis of the reservoir fisheries in Sri Lanka. A report for the Project TCP/SRL/8804 Development of Fisheries in the man-made lakes and reservoirs. Based on the work of R.T.Oglesby, Fisheries Biologist. Rome, FAO, FI:TCP/SRL/8804, Field document, 2:30 p.
1981

------------, Report of the Sri Lanka aquaculture development project preparation mission (FAO/ASDB Programme). Report 2/82AS-SRL 24, 34 p.(mimeo)
1982

Fernando, A.D.N., The ground water resources of Sri Lanka. Colombo, Ministry of Irrigation, Power and Highways
1973

Fernando, C.H., The development of Ceylon's fisheries. 11. The role of inland waters in relation to the development of Ceylon's fisheries; and a note on the pearl oyster fishery. Bull.Fish. Res.Stn., Colombo, 17:291-7
1965

------------, The beach seine fishery in Ceylon's freshwaters. IPFC Curr. Aff.Bull., (50):1-21
1967

------------, The role of introduced fish in fish production in Ceylon's freshwaters. In The scientific management of animal and plant communities for conservation, edited by E. Duffey and A.S. Watt. Oxford, Blackwell Scientific Publications, pp. 295-310
1971

------------, Reservoir fisheries in South East Asia: past, present and future. Proc.IPFC, 17(3):475-80
1977

Fernando, C.H. and S.S. De Silva, Man-made lakes; ancient heritage and modern biological resource. In Ecology and biogeography of Sri Lanka, edited by C.H. Fernando. The Hague, The Netherlands, Dr. W. Junk Publishers
1984

Fernando, C.H. and J.I. Furtado, A study of some helminth parasites of freshwater fishes of Ceylon. Z.Parasitenkd., 23:141-63
1963

Fernando, C.H. and H.H.I. Indrasena, The freshwater fisheries of Ceylon. Bull.Fish.Res.Stn.,Colombo, (20):101-34
1969

Ganapati, S.V., Man-made lakes in South India. In Man-made lakes: their problems and environmental affects, edited by N.C. Ackermann, G.B. White and E.B. Worthington. Geophys.Monogr.Ser., (17): 63-73
1973

Gunatilaka, A., Phosphorous and phosphatase dynamics in Parakrama Samudra
1983 based on diurnal observations. In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, Dr. W. Junk Publishers, pp. 35-47

Gunatilaka, W.D. and C. Senaratne, Parakrama Samudra (Sri Lanka) Project
1981 a study of a tropical lake ecosystem. 2. Chemical environment with special reference to nutrients. Verh.Int.Ver.Theor.Angew. Limnol., 21:1000-6

Gwahaba, J.J., Effects of fishing on the Tilapia nilotica (Linne 1957)
1973 population in Lake George, Uganda over the past 20 years. E.Afr.Wildl.J., 11:317-28

Hettiarachchi, A., Efforts at raising fish in private ponds in the Polon-
1982 naruwa District. J.Inland Fish.,Sri Lanka, 1:115-8

Hunting Survey Corporation, A report on a survey of the resources of the
1962 Mahaweli Ganga Basin, Ceylon. Part 1. Colombo, Ceylon Government Press, 252 p.

Indrasena, H.H.A., Fresh water fishery resources. Bull.Fish.Res.Stn.,
1965 Colombo, (18):87-90

Jhingran, V.G. and V. Gopalakrishnan, Catalogue of cultivated organisms.
1974 FAO Fish.Tech.Pap., (130):83 p.

Jones, G.W. and S. Selvaratnam, Population growth and economic develop-
1972 ment in Ceylon. Colombo, Ceylon, Hansa Publishers Ltd., 249 p.

Marshall, B.E., The influence of river flow on pelagic sardine catches
1982 in Lake Kariba. J.Fish Biol., 20:465-9

Mendis, A.S., A guide to the freshwater fauna of Ceylon. Bull.Fish.Res.
1962 Stn., Colombo, (12):160 p.

------------, A preliminary study of twentyone Ceylon lakes. 2. Limnology
1965 and fish production potential. Bull.Fish.Res.Stn., Colombo, (18):7-16

------------, The role of man-made lakes in the development of fisheries
1977 in Sri Lanka. Proc.IPFC, 17(3):247-54

Moorman, F.R. and C.R. Panabokke, Soils of Ceylon: a new approach to the
1961 identification and classification of the soils of Ceylon. Trop.Agric., 117(1)

NEDECO, Mahaweli Ganga development programme implementation strategy
1979 study. Annexes A to G. Colombo, Mahaweli Development Board and NEDECO

Oglesby, R.T., Relationship of fish yield to lake phytoplankton standing
1977 crop, production and morphoedaphic factors. J.Fish.Res.Board Can., 34(12):2271-9

------------, Inland fisheries of Sri Lanka and their management. Interim
1979 report submitted to FAO, Rome, September 1979, 39p. and Appendices (mimeo)

Panabokke, C.R., Soil science, the soils of Ceylon and use of fertili-
1967 zers. Colombo

Pattiarachchi, D.B. and N.R. De Silva, Some aspects of water quality in
1972 Sri Lanka. In Proceedings of the International Hydrological Decade, National Committee of Sri Lanka. Colombo, Geological Survey Department

Petr, T. and J.M. Kapetsky, Pelagic fish and fisheries of tropical and
1983 subtropical natural lakes and reservoirs. ICLARM Newsl., (6): 9-13

Ryder, R.A., A method for estimating the potential fish production of
1965 north temperate lakes. Trans.Am.Fish.Soc., 94:214-8

------------, The morphoedaphic index - use, abuse and fundamental con-
1982 cepts. Trans.Am.Fish.Soc., 111:154-64

Schiemer, F., The Parakrama Samudra project - scope and objectives.
1983 In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, Dr. W. Junk Publishers, pp. 1-18

Schiemer, F. and A. Duncan, Parakrama Samudra project - a summary of main
1983 results. In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, Dr. W. Junk Publishers, pp. 210-8

Schiemer, F. and R. Hofer, A contribution to the ecology of the fish
1983 fauna of the Parakrama Samudra. In Limnology of Parakrama Samudra, edited by F. Schiemer. The Hague, The Netherlands, Dr. W. Junk Publishers, pp. 134-54

Schnitter, N.J., A short history of dam engineering. Water Power, 19:
1967 142-8

Senanayake, F.R. and P.B. Moyle, Conservation of the freshwater fishes of
1981 Sri Lanka. Biol.Conserv., 22:181-95

Sri Lanka, Department of Fisheries. Training course for freshwater fish-
1960 ery officers. Manuscr.Rep.Dep.Fish.Colombo, (20):69 p. (mimeo)

__________, Ministry of Land and Land Development and Mahaweli Develop-
1979 ment, Mahaweli projects and programmes. Sri Lanka, Colombo, Department of Government Printing, 124 p.

__________, Ministry of Fisheries, Master plan for the development of
1980 fisheries in Sri Lanka. Colombo, Sri Lanka, Ministry of Fisheries, 38 p.

__________, Ministry of Land and Land Development and Mahaweli Develop-
1983 ment. Mahaweli projects and programmes. Colombo. 104 p.

TAMS (Tippetts-Abbett-McCarthy-Stratton), Environmental assessment.
1980 Accelerated Mahaweli Development Programme. Vols. 1,2 and 3. New York, TAMS

Thambaiahpillay, G., Tropical cyclones and the climate of Ceylon. Univ.
1959 Ceylon Rev., 17(3-4)

Thayaparan, K., The role of seasonal tanks in the development of fresh-
1982 water fisheries in Sri Lanka. J.Inland Fish., Sri Lanka, 1: 133-67

UNDP/FAO, Master Plan (1965-1969). Mahaweli Ganga Irrigation and Hydro-
1969 power Survey, Ceylon.

U.S. Operation Mission (USOM), Mahaweli Ganga basin diversion scheme.
1961 Volume 3. Reconnaissance land classification and soil survey report. Colombo, Sri Lanka, Irrigation Department, 80 p.

Wannigama, N.D. and D.E.M. Weerakoon, Studies on cage culture of *Sarotherodon niloticus* in man-made lakes in Sri Lanka. *J.Inland*
1982 *Fish., Sri Lanka*, 1:67-85

Weerakoon, D.E.M., Induced spawning of two major species of Chinese
1979 carps, *Ctenopharyngodon idellus* and *Aristichthys nobilis* in Sri Lanka. *Bull.Fish.Res.Stn.Colombo*, (29):55-62

Weeraratne, C.S., Pesticides - an overview with particular reference to
1983 Sri Lanka. *Econ.Rev.*, 8(10):4-12

Welcomme, R.L., Observations on the biology of the introduced species of
1967 Tilapia in Lake Victoria. *Rev.Zool.Bot.Afr.*, 76:249-79

Welcomme, R.L. and D. Hagborg, Towards a model of a floodplain fish popu-
1977 lation and its fishery. *Environ.Biol.Fish*, 2:7-24

Welcomme, R.L. and H.F. Henderson, Aspects of the management of inland
1976 waters for fisheries. *FAO Fish.Tech.Pap.*, (161):36 p. Issued also in French and Spanish.

Wijeyaratne, M.S.J. and H.H. Costa, Stocking rate estimations of *Tilapia*
1981 *mossambica* fingerlings for some inland reservoirs of Sri Lanka. *Int.Rev.Gesamt.Hydrobiol.*, 66:327-33

Willey, A., Notes on the freshwater fisheries of Ceylon. *Spolia Zeylan.*,
1910 7:88-105

Anon, The Mahaweli project. *Econ.Rev.*, 4(8-9):4-22
1978

__________, Fisheries. *Econ.Rev.*, 9(3):3-16
1983

M-43
ISBN 92-5-102327-1